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Effects of Practice on Variability, Effects of Variability on Transfer

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Five experiments examined how practice early in skill acquisition affected variability and accuracy during skill retention (Experiments 1–5) and skill transfer (Experiments 3, 4, 5). Lag constraints required that each path from apex to base of a computer-generated pyramid display differ from some number (the lag) of immediately prior paths. Location constraints specified end points at which paths must exit the pyramid. In all experiments, an early optimal period for acquiring a variability level was identified. Both low and high levels of variability were sustained during retention; high levels facilitated transfer. The results suggest that (a) early practice that requires high variability sensitizes learners to changes in condition and (b) such perception–performance links facilitate transfer by activating appropriate alternative strategies/schema or initiating their construction.

Keywords: variability, practice, transfer

An important research area in skill acquisition involves the effects of early practice on the contents of learning and how easily that learning transfers to novel tasks. Variability, understood as the number of different ways in which something is done, appears central to this research. The general finding is that training that requires greater differences in responding—random/repeat-blocked versus blocked practice (Proteau, Blandin, Alain, & Dorion, 1994), variable versus consistent practice (Carlson & Yaure, 1990), easy versus difficult discriminations (Doane, Alderton, Sohn, & Pellegrino, 1996)—is less effective during early practice but more effective during skill retention or skill transfer. Hypotheses explaining these results also imply variability: greater flexibility in reinstating or recombining elements of a skill repertoire (Lee & Magill, 1983); more exhaustive search strategies (Doane, Sohn, & Schreiber, 1999); richer sets of retrieval cues (Shea & Morgan, 1979).

The present study aims to expand our knowledge about practice effects in three ways: first, by adapting learned variability protocols (Stokes & Balsam, 2001; Stokes & Harrison, 2002) to study transfer; second, by introducing a new practice condition; third, by determining if high variability is advantageous to transfer because participants learn how to alter a basic task and/or when to make such alterations. "How" may include shifting between specific responses, amending a default rule/strategy (Holland, Holyoak, Nisbett, & Thagard, 1987), or shifting the parameters of a generalized response/motor program (Schmidt, 1975). "When" implies sensitivity to changes in conditions or contingencies (Gopher, Weil, & Siegel, 1989; Joyce, & Chase, 1990; Mayfield & Chase, 2002; Simon, 1988). For example, given three different ways (how) to move a stylus, effective performance depends on noticing a necessity (when) to shift between, combine, or alter the movements.

We begin by reviewing work from the cognitive development and learning literatures that focus on variability.

Variability and Cognitive Development

Obviously not everyone learns at the same pace. The gifted and talented thrive on accelerated curricula, whereas other students require additional practice to acquire a new skill or concept (VanTassel-Baska, 2000; Winner, 1996). However, extended or consistent practice per se has undesirable educational consequences. One is poor transfer to novel problems, a result that has been attributed to a number of different things, including inflexible response patterns (Shea, Kohl, & Indermill, 1990), insensitivity to changed contingencies (Joyce & Chase, 1990), inability to discriminate when to switch between responses (Mayfield & Chase, 2002), and decreased malleability of strategic skills (Doane et al., 1996; Duncker, 1945).

Another possibility, posed by this article, is the acquisition of habitually low variability levels in the skill domain (Stokes & Balsam, 2001; Stokes, Mechner, & Balsam, 1999). The reason low variability is undesirable is straightforward: At all levels of cognitive development, higher variability facilitates learning.

High variability facilitates learning. Young children who initially use more strategies while developing their mathematical (Carpenter & Moser, 1982; Siegler, 1996), grammatical (Bowerman, 1982), conservation (Church & Goldin-Meadow, 1986; Goldin-Meadow, 1997), or sorting (Coyle & Bjorkland, 1997) skills acquire new strategies faster. For example, a child can add 3 + 5 using several different strategies. If young enough, he or she might simply guess. If older and more experienced with numbers, he or she could retrieve the answer from memory. In between, using the "sum" strategy, he or she could count up to 3 on one hand, up to 5 on the other, and then count up all the fingers that are

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raised. Children who use more strategies prior to acquiring the more sophisticated Min strategy (counting up from the higher addend, here the "5" in "3 + 5"), acquire it sooner than those who used fewer strategies (Siegler & Jenkins, 1989). Children who acquire motor skills under variable compared to consistent practice conditions—for example, learning to toss a shuttlecock (Moxley, 1979) or beanbag (Kerr & Booth, 1978) from several locations (variable practice) versus only one (consistent practice)—perform better on transfer tasks.

Among professional athletes or musicians, varying deliberately in performance depends on having practiced in highly variable ways (Sloboda, 1996). For example, in learning a set of Mozart variations, a pianist might play the right and left hand notes separately or together, staccato (bouncing off a note) or sustenuto (holding on), piano (softly) or forte (loudly), with or without pedaling, allegretto (quickly) or legato (slowly). Notice that mastery is being acquired not only in accurately producing the series of notes but also in multiple ways of producing them, all of which improve with the practice.

Experimental work has shown that young adults learning to press keys (Simon & Bjork, 2002), to toss tennis balls in particular patterns (Shea & Morgan, 1979), to program in LISP (Anderson, 1993; Anderson, Conrad, & Corbett, 1989), or to play basketball (Hall, Domingues, & Cavazos, 1994), badminton (Goode & Magill, 1986) or the piano (Sloboda, 1996) also profit from practice conditions that require greater variability. More variable conditions include random (vs. blocked) as well as variable (vs. consistent) practice.

Variability persists after skills are learned. With mastery of motor skills, variability decreases in some aspects of performance and increases in others; that is, the locus of the variability shifts, but not the level. For example, as children's grasping or timing skills mature, general action patterns (or macrostructures) become stable, whereas individual response components (or microstructures) remain variable. This residual (as opposed to error) variability is functional because it allows the individual to adapt to different requirements by reorganizing his or her skills (Manoel and Connolly, 1995, 1997).

With mastery of cognitive skills, like arithmetic, more efficient or sophisticated strategies are used more often than less efficient ones, but variability—measured as the number of strategies used on a problem set—remains stable (Siegler & Jenkins, 1989; Siegler, 1996). Adults too continue to use multiple (correct) strategies when doing simple arithmetic. Here, the most frequently used strategies are decomposition (e.g., substituting 10 for 9 and then subtracting one from the sum: 9 + 8 = 10 + 8 – 1), counting, and retrieval (Geary & Wiley, 1991; LeFevre, Smith-Chant, Hiscock, Daley, & Morris, 2003).

The Learned-Variability Model

Variability, like persistence (Eisenberger, 1992), originality (Eisenberger & Cameron, 1998), form (Stokes & Balsam, 1991). and rate (Weiner, 1969) of responding, is the product of reinforcement history (Neuringer, 2002; Page & Neuringer, 1985). That is, variability levels associated with early success become selectively maintained aspects of skilled responding (Stokes, 1995, 1999; Stokes & Balsam, 2001).

This means that learning how to do something includes learning how differently to go about doing it. The *how* is the skill, the *how differently* is the variability level. In the learned-variability model, problem difficulty is determined by task constraints, which specify how something can be done, and variability constraints (referred to as *lag constraints* in the present article[1]), which specify how differently it must be done. These constraints can be explicit (learned via instruction) or implicit (learned via consequences). Encountered *early* in skill acquisition, *constraints* and the *degree of difficulty* in *mastering* them contribute to the acquisition of default rules or strategies that establish *habitual variability* levels in a domain. The italicized terms are elaborated on in the following paragraphs.

Habitual variability levels are preferred performance ranges in a domain (Stokes & Harrison, 2002). For example, when making causal attributions (Kuhn & Phelps, 1982; Schauble, 1990) or doing arithmetic (Carpenter & Moser, 1982; Fuson, 1982; Siegler, 1996), the range or number of strategies an individual child uses does not diminish when more efficient strategies are learned. Rather, variability is maintained by shifting the distribution (e.g., using more efficient strategies more often) but not the number of strategies used. For example, a child who habitually uses three strategies in addition may begin a school year by switching between guessing, retrieving, and counting all the digits involved. By the end of the year, the same child could be switching (correctly) between retrieving, counting all, and counting from the higher addend. As mentioned earlier, adults also habitually use multiple strategies (counting, retrieval, decomposition) when solving simple arithmetic problems (LeFevre et al., 2003).

Pressure to maintain the equilibrium of a learned variability level comes from the dual discomforts of anxiety (felt when current variability requirements are higher than the habitual level) and boredom (felt when requirements are lower than the habitual level). If anxiety or boredom motivates an individual to regain a habitual variability level, variability shifts due to changed constraints should not last (Stokes, 2005). Indeed, multiple studies show that they do not. Variability levels increase temporarily when novel contingencies are encountered later in training by college students (Stokes, 1995; Stokes & Balsam, 2001; Stokes & Barad, 2007), when new strategies are acquired by children (Goldin-Meadow, Alibali, & Church, 1993; Siegler & Jenkins, 1989), or when novice-to-expert transitions occur in adults (Johnson et al., 1981; Lesgold et al, 1988). After a new requirement is mastered, variability returns to the level seen prior to its introduction.

In the learning and cognitive development literatures, a strategy is defined as a response selected from a set of alternatives to reach a specified goal (Siegler, 1996; Wong, 1977). Strategies in a set are arranged hierarchically: The one with the greatest early success and most general condition becomes the default rule (Holland et al., 1987).

Default rules may specify variability ranges per se or response patterns that generate and maintain a particular level. For example, a default that specified alternating between two response se-

[1] The term *lag constraints* is used lest confusion arise because variability refers to both an independent variable (a constraint), and a dependent variable (a level). A lag is a number indicating from how many prior responses a current response must differ.

quences would generate lower variability than one requiring alternating between four or five paths. Using a maze game similar to the ones in the current study, Stokes and Harrison (2002) reported a high-variability default rule, which they called the wedge pattern. Left and right presses on a computer keyboard produced the paths through the maze. The pattern appeared when the number of left or right presses increased or decreased by one in each successive path, e.g., RRRRR, RRRR*L*, RRR*LL*, etc. Each successive path was different, making response variability very high.

Strategies below the default in a hierarchy have more specific conditions and are called exception rules. Exception rules are closely related to their defaults (Stokes & Barad, 2007). If our learner was a child and his or her goal was correctly adding two single-digit numbers (2 + 3), the default rule might be "if adding two numbers, then count up all the digits" (1, 2, 3, 4, 5). However, if one number was much larger than the other (2 + 7), he or she might also acquire an exception rule like "if adding two numbers and one is larger, then count up from the large number" (7, 8, 9).

Early refers to an optimal period for acquiring a problem representation (and default rule) in a specific task or domain. Given that more or less experience is required to establish a problem representation, different problems will have earlier or later optimal periods.

Stokes & Balsam (2001) showed that exposure to a very high variability requirement shortly after students learned how to play a computer game sustained high variability when the constraint was relaxed. Requiring high variability at other times (sooner or later) did not have a sustained effect. If the requirement was introduced at the start of training, students tried many things but very often failed to meet the requirement. Because high variability was not rewarded, it was not maintained. If introduced later in training, variability increased temporarily but then returned to the lower (initially rewarded) level when the constraint was removed. The optimal period in this experiment occurred shortly after the rudiments of the task were learned and a change in constraint lowered the reward level. Aspects of responding that helped reinstate reward—including higher variability and the strategy that specified it—were selectively maintained.

A number of studies that did not manipulate variability per se parallel these results. Using a motor task, Lai, Shea, Wulf, and Wright (2000) switched type of practice halfway through acquisition (after the 54th trial). In both retention and transfer tasks, global errors were lower in the Constant-to-Variable group, which learned to vary after mastering its basic task, than in the Variable-to-Constant group, which did not master its initial tasks. Visual discrimination studies also provide evidence that early training conditions determine default strategies (Doane et al., 1996; Pellegrino, Doane, Fischer, & Alderton, 1991). Participants trained under initially difficult discriminations appear to acquire precise comparison strategies that facilitate transfer, whereas those trained under initially easy discriminations learn more global strategies that hinder transfer (Doane et al., 1996). Because precise strategies involve more comparison points and therefore greater search, we surmise that they generate more variable responding than global strategies with fewer points of comparison.

Constraints are defined in their problem-solving sense as both limiting and directing search (Reitman, 1965). This means that constraints are two-sided, precluding some responses in order to promote others. Constraints that increase variability do so by precluding the reliable or predictable and promoting the novel or unpredictable. Two kinds of constraints known to affect variability are task and variability constraints.

Task constraints define skill domains and involve materials and conventions concerning their use. They affect variability by specifying how differently a task can be done, that is, which responses are permissible. Given alternative responses, variability constraints specify how differently the task must be done. (For a more complete discussion, see Stokes & Harrison, 2002).

Degrees of difficulty determine levels of variability. More difficult constraints generate higher variability than less difficult ones. Theoretically, this is because harder problems generate greater search in a problem space for solution, ergo higher variability. Easier problems lead to less extensive search (Newell & Simon, 1972). Empirically, this has been demonstrated in multiple studies using lag procedures, in which a response is rewarded if it differs from some number of prior responses. (See Neuringer, 2002, for a review.) For example, with response pairs and a Lag-2 requirement, reward would follow AA, AB, BA, because the third pair differs from the two prior ones. It would not follow BA, AA, BA or AA, BA, BA, because the third pair repeats the first or second. Problem difficulty and variability increase as lag values increase (Stokes, 1999).

Other studies have shown that identical problems presented with different instructions (Hackenberg & Joker, 1994; Joyce & Chase, 1990; Kramer, Larish, Weber, & Bardell, 1999; LeFrancois, Chase, & Joyce,1988; Stokes & Balsam, 2003) or at different times in training (Lee & Magill, 1983; Schmidt & Bjork, 1992; Shea et al., 1990; Shea & Morgan, 1979; Stokes, 1995, 1999; Stokes & Balsam, 2001; Stokes et al., 1999), are more or less difficult to solve.

Mastering of early constraints is very important. Only variability levels that lead to, and thus are associated with, early success are maintained. In short, operant conditioning is responsible for variability levels becoming habitual (i.e., generated and maintained by default rules). Although our focus is on high variability, the same mechanism accounts for the acquisition of low variability levels that, in cases like data entry or laser surgery, can be both desirable and functional. Initial success doing few things, or initial failure doing many, will lead to low variability in a domain.

The Current Study: Overview of Experiments

The present study used several versions of a computer maze game for (a) adapting learned variability protocols to study transfer, (b) introducing a new practice protocol, and (c) determining if high learned variability levels are advantageous because participants learn how to alter a basic task and/or because they become more sensitive to changes in contingency (i.e., learn when to alter the basic task).

Figure 1 presents one version of the game (used in Experiments 1–3), which requires seven presses on the left and/or right arrow keys to move the white diamond from the apex to the bottom of the triangle (hereafter referred to as the pyramid).

In this size pyramid there are 128 unique right-left paths from top to bottom. Participants earn points for taking correct paths through the pyramid. Correctness depends on two things: a location (task) constraint identifying the end point at which a path must end (identified by the letters A to H at the base of the triangle), and

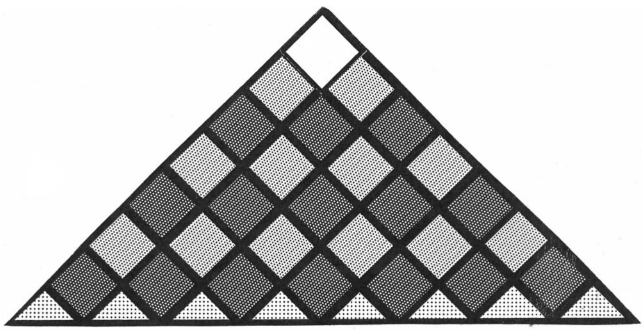

Figure 1. The 7-pyramid display. Letters identify end-point locations. Numbers in parenthesis indicate how many paths lead to each location.

location plus a lag (variability) constraint specifying from how many prior paths (the lag) a current path must differ.

During *location-only* practice, a series of location constraints designating 1, 2, or 3 end-point locations was is in effect. Note that although a lag constraint was not in effect, few or many different paths may be taken to specified end points (numbers under each letter in Figure 1 indicate how many paths lead to each). During *lag* practice, a series of lag constraints required that these end-point locations be reached by paths that differ from one, two, or five prior paths. During *alternating practice*, a lag constraint was added to a just-mastered location constraint. With Lag 2, for example, after a specified number of points were earned for exiting at location E on Figure 1, participants could only earn that number of additional points if they reached the same-end-point location (E) by a path different from their last two paths. As the game progressed, the number of allowed end-point locations decreased and the size of the lags increased.

Note that the procedure resembles a random versus blocked, rather than a variability versus consistent, practice protocol. Blocked practice includes a fixed number of different tasks. For example, with three tasks (A, B, C) consisting of different movement sequences, a blocked group would practice each task separately and successively (i.e., AAA–BBB–CCC), whereas a random group would practice the same tasks in a quasirandom order (e.g., A-BB-A-C-B-CC-A). Tasks are held constant in both groups; ordering of tasks differs between the groups. In the current experiments,[2] end-point locations were held constant in all groups; presence or absence of lags differentiated the groups.

Experiments 1 and 2 examined the effects of practice on variability during *acquisition*, or training, and *retention*. Experiment 1 introduced the alternating practice protocol, comparing its effects with location-only and lag practice during acquisition and retention. Experiment 2 tested a modified version of alternating practice.

Experiments 3, 4, and 5 examined the effects of variability derived from different practice regimes on retention of variability levels and *transfer* of skill. Experiment 3 looked at acquisition, transfer, and retention (in that order and with very short delays between each phase). Experiments 4 and 5 were designed to more closely replicate motor paradigms by using an acquisition-retention-transfer design (with a longer delay period and different task inserted between retention and transfer).

Experiment 1: Effects of Sustained Alternating Practice on Variability and Accuracy

As discussed earlier, some students cannot successfully solve difficult problems or master complex skills early in training. However, these learners are done a disservice if they are simply given less difficult problems or extended practice on a particular problem. In such situations, they may well master the material at hand, but without acquiring the higher variability levels that facilitate acquisition of novel strategies (Siegler, 1996) or successful solution of novel problems (Schmidt & Bjork, 1992). Two hypotheses were tested.

One involved kind of practice. We predicted that multiple alternations between location-only and lag practice (at the same location or locations) might allow students to attain mastery/accuracy and sustain levels of variability similar to those acquired under lag practice.[3] In the current experiment, alternating practice involved reiteratively adding a lag constraint to a just-mastered location constraint.

A second prediction, based on evidence of optimal periods for establishing habitual variability levels (Stokes & Balsam, 2001), was that early variability levels would correlate positively with levels at the end of retention (when the constraints were identical in all groups). Note that retention in this study refers to maintaining a learned variability level.

Method

Participants

Thirty female Barnard College undergraduates participated to fulfill an Introductory Psychology class requirement.

Apparatus and Stimuli

Five personal computers, in separate 1.5m × 3.5m experimental rooms, were used. As shown in Figure 1, the display was a computer-generated triangle/pyramid with 128 paths from apex to base and eight exits, or end points (triangles), on the base. In the figure, end points are identified by letters (A–H). Numbers under the letters indicate how many different paths lead to each end point.

Pressing the left or right directional arrows moved the white diamond at the apex downward to the left or the right. Seven presses completed a path. When the diamond reached an end point, the pyramid disappeared and the words "1 point" (for correct paths) or "0 points" (for incorrect ones) and a cumulative total appeared, along with the instruction "press enter to continue." When the Enter key was pressed, the pyramid reappeared. At the end of the game, the words "the session is over" appeared on the screen.

Procedure

Participants were randomly assigned to one of three experimental groups playing different versions of the computer game. Loca-

[2] There is one exception (Extended group, Experiment 2).

[3] We relate this work to single alternation conditions in the motor literature (e.g., Lai et al., 2000) in the General Discussion.

tion constraints specified end points for paths. Lag constraints specified the number of prior paths from which a current path had to differ. The game ended when a total of 400 points was earned.

Table 1 shows the sequence of location (L) or combined location–lag (L–V) constraints for each group in Experiment 1. In each block, 25 points were earned: Blocks included correct (reinforced) and incorrect trials. Table 2 presents the exact constraint requirements.

Instructions. After reading and signing a consent form, participants were brought into the experimental rooms and read the following instructions:

"The purpose of this experiment is to see how simple motor tasks are learned. You have been assigned to a group that gets feedback from the computer. Your task is to earn points by generating key press sequences. You can use two keys—the left and right directional arrows. After a correct sequence, a point will appear on the screen. Please do not hold the keys down. You must press a key and let it go. When the program stops, please come and get me."

Acquisition. To earn 300 points during acquisition, the Location-Only group met the location constraints only; the Lag-practice group met the combined location–lag constraints; the Alternating-practice group alternated between the constraints met by the other two groups. For example, in Block 1 (Trials 1–25), its requirements were identical to the Location-Only group. In Block 2 (Trials 26–50), its requirements matched those of the Lag group.

Retention. One hundred points were earned during the final 4 blocks (Blocks 13–16). As in acquisition, these were divided into blocks of 25 reinforced trials each. During these blocks, all groups met the same location constraint.

Debriefing. There was no time limit for earning the 400 points. Participants were debriefed at the end of the experiment. During the debriefing, they were asked how they earned points and if what they had to do changed during the experiment.

Measures and Analyses

Variability. Percentage of different paths is our measure of variability. This percentage was calculated for each block by dividing the number of different paths (correct and incorrect) by the total number of paths (correct and incorrect) in that block. For example, with 5 different paths and a total of 25 paths, percentage different would be 20% (5/25). Mixed two-way analyses of variance (ANOVAs) with *practice group* and *block* as factors were used to compare variability levels. Fisher's least significance (LSD) test was used for post hoc comparisons. The significance level was .05. Pearson correlations were run between the last blocks in acquisition and retention to determine if learned variability levels were sustained.

Accuracy. Percentage of correct paths is our measure of accuracy. This percentage was calculated for each block by dividing the required number of correct paths in a block by the total number of paths (correct and incorrect) taken in that block. If a participant took 5 incorrect paths (for a total of 30) in a 25-point block, percentage correct would be 83% (25/30). Mixed two-way ANOVAs and Fisher's LSD test were used to compare accuracy levels.

Optimal period. Pearson correlations were run between the early blocks of acquisition and the last block in retention (Block 16) to determine if early levels of variability (a result of problem difficulty) were positively related to variability levels at the end of training.

Results

The experiment lasted for 400 reinforced trials. For purposes of analyses, these were divided into blocks of 25 reinforced trials each. Only the first and the last blocks of 25 reinforced trials during the final common location constraint (retention) were included in the analyses. Because blocks included both accurate (reinforced) and incorrect (nonreinforced) paths, percentages were calculated for group comparisons.

The top and bottom panels of Figure 2 present mean percentages of different and correct paths through the 7-pyramid during all of acquisition (Blocks 1 through 12) and the first (Block 13) and last (Block 16) blocks of retention.

Variability. The two-way ANOVA for percentage of different paths during acquisition showed main effects of block, $F(11, 17) = 4.940$, $p < .01$, $n^2 = .762$, and group, $F(2, 27) = 23.068$, $p < .01$, $n^2 = .631$, as well as a significant Block $\times$ Group interaction, $F(22, 36) = 2.055$, $p < .05$, $n^2 = .557$. LSD tests showed that the Location-Only group was less variable than either the Lag or Alternating group (both ps $< .01$). With the successive changes in constraints, variability fluctuated during acquisition, with greater decreases in the Location-Only group.

To determine if students were aware that the location constraint was relaxed during retention, we calculated how many exited the pyramid at locations other than the single end point required during the last acquisition block (End Point E). The percentage of students in each group who switched to different end points at the start (Block 13) and end (Block 16) of retention are shown in Table 3.

Table 1
Block-by-Block Requirements: Experiment 1

	Blocks												
	Acquisition												Retention
Group	1	2	3	4	5	6	7	8	9	10	11	12	13/16
Location-only	**L1**	L1	L2	L2	L3	L3	L4	L4	L5	L5	L6	L6	L7
Alternating	**L1**	**L1-V1**	L2	L2-V1	L3	L3-V2	L4	L4-V2	L5	L5-V3	L6	L6-V3	L7
Lag	L1-V1	**L1-V1**	L2-V1	L2-V1	L3-V2	L3-V2	L4-V2	L4-V2	L5-V3	L5-V3	L6-V3	L6-V3	L7

Note. L = location constraints; V = lag constraints. For values of L1-L7 and V1-V3, see Table 2. Boldface indicates how the alternating group was like both the location-only and lag groups.

Table 2
Location and Lag Constraints

Location constraints	Lag constraints
L1 = 3 endpoints (BDF)	V1 = current path had to differ from 1 prior path (lag1)
L2 = 3 endpoints (CEG)	V2 = current path had to differ from 2 prior paths (lag2)
L3 = 2 endpoints (BF)	V3 = current path had to differ from 5 prior paths (lag5)
L4 = 2 endpoints (CG)	
L5 = 1 endpoint (D)	
L6 = 1 endpoint (E)	
L7 = 6 endpoints (BCDEF)	

Note. Location constraints are indicated by the letter L (for location) with the numbers 1 through 7. Lag constraints are represented by the letter V (for higher required variability) and the numbers 1, 2, and 3. Letters in parentheses identify end points, as shown in Figure 1.

Between the start and end of retention, the two-way ANOVA generated a main effect of group, $F(2, 27) = 26.079$, $p < .01$, $n^2 = .659$). LSD tests showed that the Location-Only group was less variable than the Lag and Alternating groups. Recall that retention refers to maintaining a learned variability level. This was shown by the significant results of a Pearson correlation between the last blocks in acquisition (Block 12) and retention (Block 16; $r = .779$, $p < .01$).

Accuracy. The two-way ANOVA for percentage of correct paths taken during acquisition showed main effects of block, $F(11, 17) = 12.749$, $p < .01$, $n^2 = .892$, and group, $F(2, 27) = 31.717$, $p < .01$, $n^2 = .701$. LSD tests showed that the Location-Only

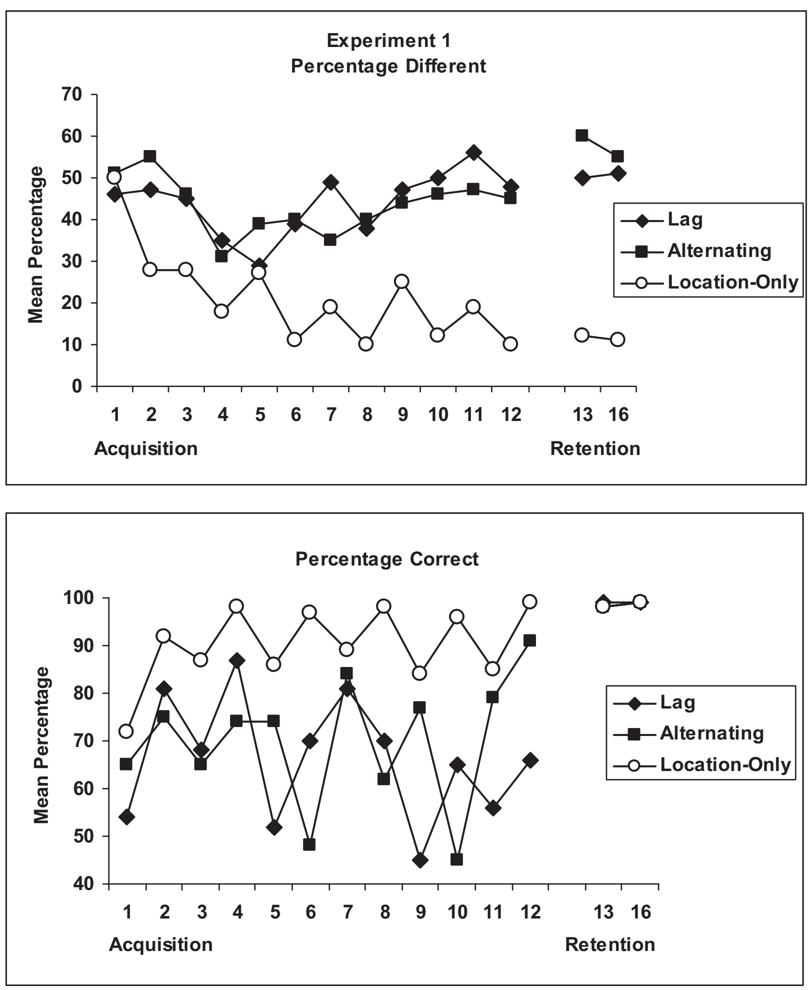

Figure 2. Variability (percentage of different paths) and accuracy (percentage of correct paths) for Lag, Alternating, and Location-Only groups in Experiment 1.

Table 3
Switches in End Points From the End of Acquisition Through Retention

Experiment	Group	Percentage switching	
		Start retention	End retention
1	Lag	70%	100%
	Alternating	70%	90%
	Location-Only	70%	90%
2	Alternating	60%	100%
	Extended	73%	100%
	Location-Only	60%	73%
4	Lag	90%	90%
	Location-Only	100%	100%
5	Lag	100%	100%
	Location-Only	100%	100%

Note. Data are not included for Experiment 3 because retention required going to end points different from the final block in acquisition.

group was significantly more accurate than either the Lag or Alternating groups (*p*s for both <.01). The interaction (Block × Group) was also significant, $F(22, 36) = 4.215$, $p < .01$, $n^2 = .720$. As seen in Figure 2, although accuracy levels increased and decreased with constraint changes, they were lower in the two groups with lag requirements (Lag and Alternating).

The two-way ANOVA for the first and last blocks of retention, when points could be earned for paths that ended at any previously required location (A through G) produced no significant between-group differences. All participants earned almost 100% of the 25 possible points in both blocks.

Optimal period. The Pearson correlation run between percentage of different paths during Block 2 in acquisition and Block 16 in retention showed that early variability was positively related to later variability ($r = .407$ $p < .05$).

Self-Reports. During debriefing, students reported what they did to earn points. Their responses were sorted into the three categories: end points, patterns (paths), and vary patterns to same end point (see Table 4).

Recall that location constraints involved end points; lag constraints, taking different paths to specified end points. The majority of the Alternating and Location-Only groups mentioned end points alone. Students referred to end points as exits, hot spots, blocks, or boxes on the bottom. The most frequent response in the Lag group involved paths, which students referred to as patterns. The combined and most specific category, Vary Patterns to Same End Point, was only reported by students in the Lag and Alternating groups.

Discussion

Our main questions concerned the effects of different kinds of practice on variability and accuracy. The three practice conditions differed in whether and when lag constraints were added to location constraints.

Did differences in practice affect variability and accuracy? Yes. During acquisition and retention, variability (percentage of different paths) was higher in the Lag and the Alternating groups than in the Location-Only group. Accuracy (percentage of correct paths) was highest in the Location-Only group during acquisition, but equal in all three groups during retention when their task constraints were identical.

Did early levels of variability predict later ones? Yes. Variability during Block 2 of acquisition (the optimal period in learned-variability theory) was positively correlated with variability at the end of retention (Block 16). Because task constraints during Block 16 were identical for all groups, early constraints and not current ones appear responsible for the sustained variability differences seen in the top panel of Figure 2.

However, alternative explanations for the equivalence of Alternating and Lag practice are suggested by this experiment. One involves intermittent lags, which may help maintain high variability because subjects expect their recurrence. Another involves number of switches between novel constraints. Block 2 (the optimal period) was when the first switch took place for the Alternating group; no switch had yet occurred for the Lag or the Location-Only groups. Because variability generally increases with any change in constraint, how often constraints shift may be important. Overall, there were only 6 constraint shifts in the Lag group; there were 11 in the Alternating group. All shifts were to novel constraints (location and/or lag).

In sum, performance in the Alternating group could have depended on high variability during the optimal period, on intermittent lags, or on multiple shifts between novel constraints. Experiment 2 explored these possibilities.

Table 4
Self-Reports of What Students Did To Earn Points, in Percentages, by Category

Experiment and group	Categories		
	End points	Patterns (paths)	Vary patterns to same end point
Experiment 1			
Lag	30	**40**	30
Alternating	**70**	0	30
Location-Only	**80**	20	0
Experiment 2			
Alternating	27	27	**46**
Extended	20	33	**47**
Location-Only	67	33	0
Experiment 3			
Lag	20	10	**70**
Alternating	20	20	**60**
Location-Only	40	**60**	0
Experiment 4			
Lag	**50**	20	30
Location-Only	**50**	30	20
Experiment 5			
Lag	10	30	**60**
Location-Only	**100**	0	0
Overall			
Lag	28	25	**47**
Alternating	39	16	**45**
Extended	20	33	**47**
Location-Only	**67**	29	4

Note. The greatest percentage category for each group is in boldface.

Experiment 2: Effects of Novel and Repeated Constraints During Acquisition on Variability

To manipulate the number of novel constraints during acquisition, practice in the Alternating protocol was changed for a fourth group of students, called the Extended group, which received extended practice. In the protocol for this group, the sequence of location followed by location–location-plus-lag was repeated. That is, instead of Blocks 1–4 being L1, L1–V1, L2, L2–V2, as with the Alternating group, they were L1, L1–V1, L1, L1–V1. This repetition meant there were fewer novel constraints for the Extended group. To diminish expectations of continued intermittent lags, the Retention period (without any lags) was extended from 100 reinforced trials to 250.

The following predictions were made. First, if number of new constraints is important to sustaining high variability levels, the Alternating group should be more variable than the Extended group during acquisition and retention. Second, if extended retention reduces variability in both Alternating and Extended groups, then the results of Experiment 1 (for the Alternating group) may be due to anticipating lag constraints over a shorter number of trials without lags. Third, as in Experiment 1, the Location-Only-practice group should be the most accurate during acquisition and least variable during both acquisition and retention.

Method

Participants

Forty-five Barnard and Columbia College students (42 women, 3 men) participated to fulfill an Introductory Psychology class requirement.

Apparatus and Stimuli

These were identical to those in Experiment 1.

Procedure

The instructions used in Experiment 1 were read to all participants, who were randomly assigned to one of three groups: Alternating, Extended, and Location-Only. Location and lag constraints were identical to those in Experiment 1 (see Table 2). The constraint sequences for the Location-Only- and Alternating-practice groups were identical to groups with the same names in Experiment 1. The Alternating and Extended groups switched between location-only and location-plus-lag requirements. The new Extended-practice group was exposed to only three sets of paired location→location–lag constraints prior to the common location-only constraint in retention; each set was repeated once before proceeding to the next set. The Alternating group met six sets of location constraints. The Location-Only group met location constraints.

Constraint sequences for all groups are shown in Table 5.

There was no time limit for earning the 550 points (acquisition, 300 points; retention, 250 points). At the end of the experiment, participants were debriefed and asked what they did to earn points and if this changed during the experiment.

Analyses

The 550 reinforced trials were divided into blocks of 25 reinforced trials each. Only the first and last blocks of 25 reinforced trials during the final shared location constraint (retention) were included in the analyses. Because blocks included both accurate (reinforced) and incorrect (nonreinforced) paths, percentages were calculated for group comparisons. Mixed two-way ANOVAs with practice group and block as variables were used to compare responding throughout training. Fisher's LSD test was used for post hoc comparisons. The significance level was .05.

Pearson correlations were run between the last blocks in acquisition and retention to determine if learned variability levels were sustained. They were also run between the early blocks of acquisition and the last block of retention to determine if early variability correlated with variability at the end of training.

Results

The top and bottom panels of Figure 3 present mean percentages of different and correct paths through the 7-pyramid during all acquisition (Blocks 1 through 12) and the first (Block 13) and last (Block 22) blocks of retention.

Variability. During acquisition, the two-way ANOVA for percentage of different paths showed main effects of block, $F(11, 32) = 5.921$, $p < .01$, $n^2 = .671$, and group, $F(2, 42) = 13.711$, $p < .01$, $n^2 = .395$. LSD tests showed that the Location-Only group was significantly less variable than either the Alternating or Extended groups (*p*s for both <.01). The interaction (Block × Group) was also significant, $F(22, 66) = 2.716$, $p < .01$, $n^2 = .475$. As in Experiment 1, variability levels shifted upward or

Table 5
Block-by-Block Requirements: Experiment 2

	Blocks												
	Acquisition												Retention
Group	1	2	3	4	5	6	7	8	9	10	11	12	13/22
Location-only	L1	L1	L2	L2	L3	L3	L4	L4	L5	L5	L6	L6	L7
Alternating	**L1**	**L1-V1**	**L2**	**L2**-V1	L3	L3-V2	L4	L4-V2	L5	L5-V3	L6	L6-V3	L7
Extended	**L1**	**L1-V1**	**L1**	**L1**-V1	L4	L4-V2	L4	L4-V2	L6	L6-V3	L6	L6-V3	L7

Note. L = location constraints; V = lag constraints. For values of L1-L7 and V1-V3, see Table 2. Boldface indicates how the Alternating and Extended groups differed in location constraints.

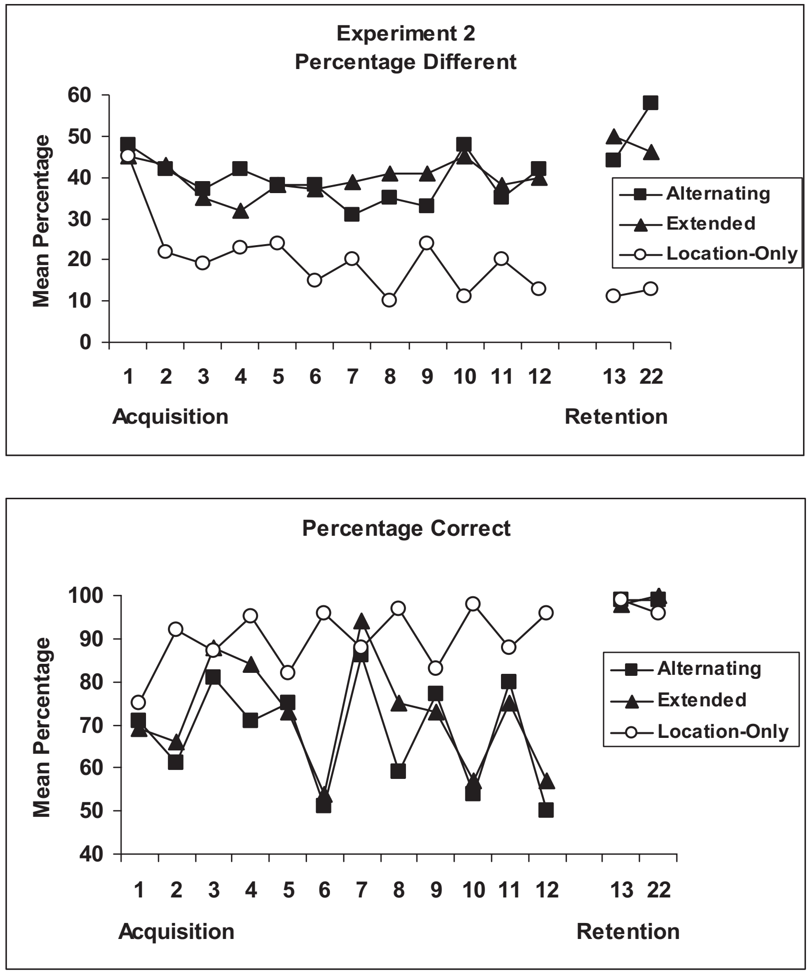

Figure 3. Variability (percentage of different paths) and accuracy (percentage of correct paths) for Alternating, Extended, and Location-Only groups in Experiment 2.

downward with the differing constraint changes across groups but remained higher in the two groups with lag requirements (Alternating and Extended).

To determine if students were aware that the constraints were relaxed during retention, we examined how many used exits other than the single end point required during the last acquisition block (End Point E): As seen in Table 3, the majority went to different end points during the first 25 trials of retention, 100% in the more variable groups (Alternating and Extended) did so during the last 25 trials.

Retention here refers to sustaining a variability level when the early constraints that generated the level are no longer in effect. This was shown by the significant results of a Pearson correlation between the last blocks in acquisition (Block 12) and retention (Block 22; $r = .750$, $p < .01$). The two-way ANOVA for the first and last 25-point blocks of retention produced a significant main effect for group, $F(2, 42) = 34.269$, $p < .01$, $n^2 = .620$. The LSD test showed that the Location-Only group remained less variable than either the Alternating or Extended groups (both *p*s <.01).

Accuracy. The two-way ANOVA for percentage of correct paths taken during acquisition showed main effects of block, $F(11, 32) = 25.871$, $p < .01$, $n^2 = .899$, and group, $F(2, 42) = 39.971$, $p < .01$, $n^2 = .625$. LSD tests showed that the Location-Only group was significantly more accurate than either the Alternating or Extended groups (*p*s for both <.01). The interaction (Block × Group) was also significant, $F(22, 66) = 7.254$, $p < .01$, $n^2 = .707$. As seen in Figure 3, although accuracy levels increased and decreased with constraint changes, they were lower in the two groups with lag requirements (Alternating and Extended).

The two-way ANOVA for the first and last blocks of responding during retention, when points could be earned for paths that ended at any previously required location (A through G) also produced no significant between-group differences. All groups earned almost 100% of the 25 possible points in both blocks.

Optimal period. The Pearson correlation run between percentage of different paths during Block 2 of acquisition and Block 22 in retention showed that early variability was positively related to later variability ($r = .439$ $p < .01$).

Self-Reports. As shown in Table 4, “Vary Patterns to the Same End Point” was the most frequent response for students in the Alternating and Extended groups. This category was never mentioned by those in the Location-Only group, the majority of whose responses involved end points.

Discussion

Our main questions concerned the effects of reducing the number of novel constraint changes in the Extended group and of extending the retention phase of the experiment to reduce anticipation of intermittent lags.

Did limiting the number of novel constraint changes affect variability and accuracy? No. Variability, measured as percentage of different paths, was equally high in both the Alternating and Extended groups; both were more variable than the Location-Only group, which was more accurate during acquisition but not during retention.

Did lengthening the retention phase diminish variability levels in the Alternating and Extended groups? No. As in Experiment 1, variability levels at the end of acquisition and retention were positively correlated. This result suggests that anticipation of intermittent lags is not critical to maintaining high variability.

Did early levels of variability predict later ones? Yes. As in Experiment 1, late variability was positive correlated with early variability, again supporting the idea of an early optimal period for acquiring default rules and the variability levels that they generate and maintain. The critical early block was the one in which both Extended and Alternating groups were first exposed to a variability constraint, Block 2.

The remaining questions addressed in this article are (a) how variability levels acquired under initial training affect transfer to novel tasks and (b) whether such effects depend on learning how or when to alter ways of responding to the constraint. Experiments 3, 4, and 5 deal with the effects of learned variability levels on transfer.

Experiment 3

The purpose of Experiment 3 was to determine whether learning to be highly variable facilitated transfer. To these ends, the effects of Location-Only, Alternating, and Lag practice on accuracy and variability in transfer tasks on two different sized pyramids were examined. Acquisition was shorter than in Experiments 1 and 2 because a pilot study had shown that 150 reinforced trials were sufficient to establish stable variability levels. These trials included all the basic constraints in Experiments 1 and 2: number of end points decreased (from 3 to 2 to 1) whereas lags increased (from 1 to 2 to 5).

Other procedural changes were made to address specific questions. Retention involved switching between two earlier mastered end-point locations (rather than permitting all previously rewarded end points, as in Experiments 1 and 2). This was done to see if the more variable groups became sensitive to changes in conditions. Also, unlike motor protocols, which test retention before transfer, retention was tested after transfer. This was done to see if an intervening transfer task would disrupt learned variability levels.

We predicted that the Lag and Alternating groups would be (a) more variable and less accurate during acquisition than the Location-Only group and (b) would remain more variable and becomes more accurate than the Location-Only group during transfer. We also predicted that, despite the intervening transfer task, all groups would be equally accurate during retention, although the Variable and Alternating groups would remain more variable.

Method

Participants

Thirty Barnard and Columbia College undergraduates (28 women, 2 men) participated in the experiment as part of an Introductory Psychology class requirement.

Apparatus and Stimuli

A 7-pyramid identical to the one in Experiments 1 and 2 was used during acquisition and retention. A smaller pyramid (hereafter called the 5-pyramid) with 32 different paths (compared to 128 on the larger 7-pyramid) was used during the transfer tests. In this pyramid, a total of five left or right presses moved the white box from the apex to the bottom of the pyramid. The number of paths going to each end point (Roman numbers I to VI) were:

I	II	III	IV	V	VI
1	5	10	10	5	1

Procedure

Instructions. The instructions used in Experiment 1 were modified by adding a final sentence informing students that two breaks would occur, each when the screen turned blue. They were to let the experimenter know when this occurred. The breaks occurred after acquisition and after transfer. They were required because the program required reloading whenever the pyramid display changed. The breaks were not longer than 5 min. Identical instructions were read to all participants, who were randomly assigned to one of the three groups.

Table 6 presents the sequence of location and lag constraints for both pyramids.

Twenty-five points were earned in each block. There was no time limitation for earning the total 250 points (150 acquisition; 50 each, transfer and retention).

Acquisition. The Location-Only group earned 50 points for each location constraint during training on the 7-pyramid. The Lag group earned 50 points for each location–lag constraint. The Alternating group earned 25 points for each location constraint, followed by 25 points for each location–lag constraint. There was a short break before transfer.

Transfer. All groups earned 25 points for exiting the 5-pyramid at the second end point from the right-hand side (Roman numeral V in graphic), followed by 25 points for exiting at the same location but by a path different from two prior paths. There was another short break before retention.

Retention. All groups earned 25 points for exiting the original 7-pyramid at the end-point location marked D in Figure 1, followed by earning 25 points for exiting at the location marked E. D was one of the three initial end points. E was the last end point in acquisition (Block 6).

Debriefing. At the end of the experiment, participants were debriefed and asked what they did to earn points and if what they did changed during the experiment.

Results

The top and bottom panels of Figure 4 present mean percentages of different and correct paths for all groups through the 7-pyramid

Table 6
Block-by-Block Requirements: Experiment 3

	Blocks									
	Acquisition, 7-Pyramid						Transfer, 5-Pyramid		Retention, 7-Pyramid	
Group	1	2	3	4	5	6	7	8	9	10
Location-only	L1	L1	L4	L4	L6	L6	L8	L8-V2	L5	L6
Alternating	L1	L1-V1	L4	L4-V2	L6	L6-V3	L8	L8-V2	L5	L6
Lag	L1-V1	L1-V1	L4-V2	L4-V2	L6-V3	L6-V3	L8	L8-V2	L5	L6

Note. L = location constraints; V = lag constraints. For values of L1-L7 and V1-V3, see Table 2. L8 is the 2nd end point from the right side of the 5-Pyramid.

during acquisition (Blocks 1 through 6), transfer (Blocks 7 and 8) and retention (Blocks 9 and 10) phases of Experiment 3.

The Lag group was exposed to combined location–lag constraints in all blocks during acquisition. The Alternating group alternated between location-only and location–lag requirements. The Location-Only group only had to meet location constraints. Because both correct (reinforced) and incorrect (nonrewarded) paths were included in the analyses, percentages were calculated for both different and correct paths taken in each block.

Variability. During acquisition, the two-way ANOVA for percentage of different paths showed main effects of block, $F(5, 23) = 3.674$, $p < .05$, $n^2 = .444$, and group, $F(2, 27) = 5.494$, $p <$

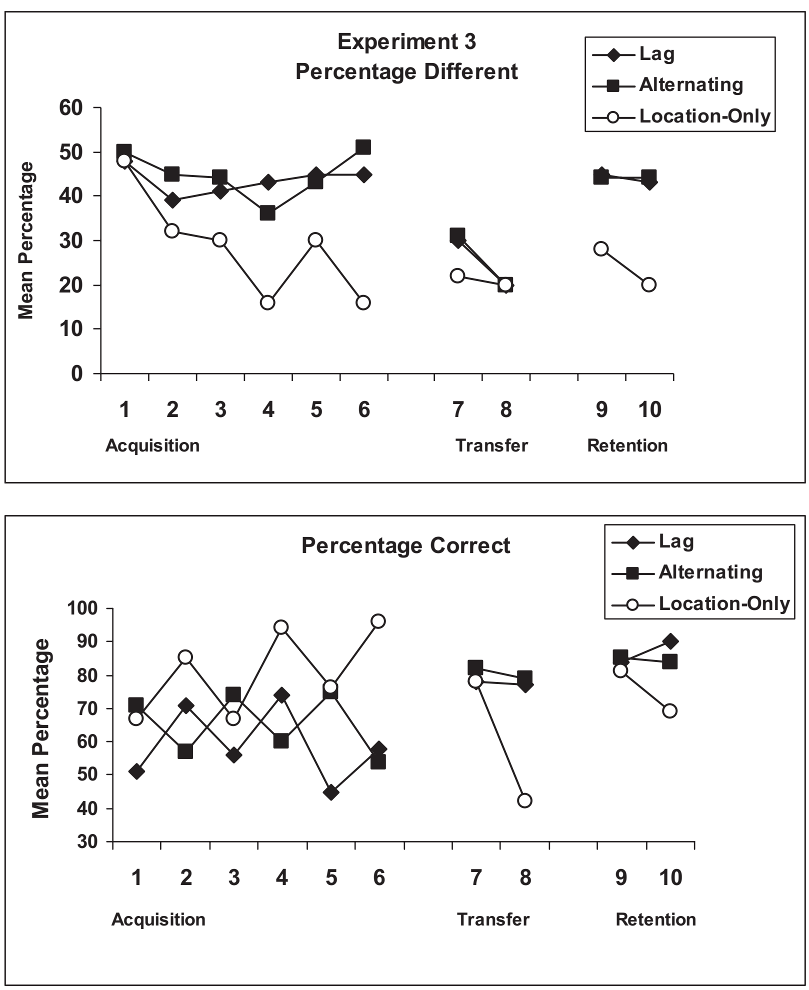

Figure 4. Variability (percentage of different paths) and accuracy (percentage of correct paths) for Lag, Alternating, and Location-Only groups in Experiment 3.

.01, $n^2 = .289$. LSD tests showed that the Location-Only group was significantly less variable than either the Lag or Alternating groups (*p*s for both <.01). The interaction (Block × Group) approached significance, $F(10, 48) = 2.020$, $p = .052$, $n^2 = .296$. Variability levels shifted up and down as the constraints changed but remained higher in the two groups with lag requirements (Lag and Alternating). During transfer, the only significant effect was for block, $F(1, 27) = 14.383$, $p < .01$, $n^2 = .348$. Variability decreased between the first and second transfer tasks.

During retention, the only significant effect was for group, $F(2, 27) = 3.919$, $p < .05$, $n^2 = .225$. LSD tests showed that the Location-Only group was less variable than the Lag or Alternating groups (both *p*s < .05). To access whether variability levels were sustained on the 7-pyramid, a Pearson correlation was run between the last blocks in acquisition (Block 6) and retention (Block 10). It was significant ($r = .557$, $p < .01$).

Accuracy. The two-way ANOVA for percentage of correct paths taken during acquisition showed main effects of block, $F(5, 23) = 6.835$, $p < .01$, $n^2 = .598$, and group, $F(2, 27) = 14.955$, $p < .01$, $n^2 = .526$. LSD tests showed that the Location-Only group was significantly more accurate than either the Lag or Alternating groups (*p*s for both <.01). The interaction (Block × Group) was also significant, $F(10, 48) = 6.590$, $p < .01$, $n^2 = .579$. As seen in Figure 4, although accuracy levels increased and decreased with constraint changes, they remained lower in the two groups with lag requirements (Lag and Alternating).

The two-way ANOVA for percentage of correct paths during transfer showed main effects of block, $F(1, 27) = 19.167$, $p < .01$, $n^2 = .415$, and group, $F(2, 27) = 11.788$, $p < .01$, $n^2 = .466$. LSD tests showed that the Location-Only group was less accurate than the Lag or Alternating groups (both *p*s < .01). The interaction (Block × Group) was also significant, $F(1, 27) = 13.085$, $p < .01$, $n^2 = .492$. Between Blocks 7 and 8, accuracy declined in the Location-Only group.

During retention, there was a main effect of group, $F(2, 27) = 3.390$, $p < .05$, $n^2 = .201$, and a significant Block × Group interaction, $F(2, 27) = 3.592$, $p < .05$, $n^2 = .210$. Accuracy declined in the Location-Only group between Blocks 9 and 10. LSD tests showed that the Lag group was significantly more accurate than the Location-Only group ($p < .05$); the difference between the Alternating and Location-Only groups approached significance ($p = .071$).

Optimal period. The Pearson correlation run between percentage of different paths during Block 2 of acquisition and Block 10 in retention showed that early variability was positively related to later variability ($r = .544$ $p < .01$).

Self-Reports. As seen in Table 4, most students in both Lag and Alternating groups mentioned taking different paths (patterns) to the same end points. Most in the Location-Only group focused on patterns; many said they repeated a pattern until it no longer earned points.

Discussion

Our questions concerned the effects of practice on learned variability levels and the effects of these levels on transfer to novel problems.

Did differences in practice affect variability and accuracy during acquisition? Yes. Variability, measured as number of different paths, was higher in the Lag and Alternating groups than in the Location-Only-practice group. Accuracy, measured as number of correct paths, was highest in the Location-Only-practice group.

Did differences in variability affect transfer and retention? Yes. The Lag- and Alternating-practice groups remained more variable but—and this is the critical finding—became more accurate during transfer tests and delayed retention than the Location-Only group.

In sum, two of our predictions were correct. During acquisition, the Lag and Alternating groups were more variable and less accurate during training than the Location-Only group. During transfer, both remained more variable but become more accurate than the Location-Only group. Our third prediction, that all groups would be equally accurate during delayed retention, was not supported: the Location-Only group was less accurate than the Lag group.

These findings provide initial support for the hypothesis that higher variability facilitates transfer. The question, of course, is how? One suggestion comes from perusing the bottom panel of Figure 4. Notice how accuracy in the Location-Only group dropped during the second task of transfer (5-pyramid) and retention (7-pyramid). This indicates that, immediately after transfer to a noticeably different display (7- to 5- to 7-pyramids), search for solution in higher and lower variability groups is more equitable. It also indicates that high variability facilitates learning when to change responding: The more variable groups switched when conditions changed in less obvious ways (i.e., the second task on each display). The alternative—learning how to alter responding—was also supported because the second transfer task involved a lag: Both high variability groups had already mastered lag constraints.

In order to disentangle these possibilities and to more closely replicate standard motor-training protocols, Experiments 4 and 5 tested retention prior to transfer. A different transfer task was used in each experiment. In order to simplify and clarify the analyses, just the Lag and Location-Only groups were included.

Experiment 4

In Experiment 4, there were two transfer tasks, the first on the smaller, 5-pyramid and the second on the larger, 7-pyramid used during acquisition. The tasks were similar to those in Experiment 3, involving first a location constraint and then adding a lag constraint to that location. This was done to replicate the results of Experiment 3 with a newly programmed pyramid game. Retention preceded transfer.

Three predictions were made: first, that the Lag group would be more variable and less accurate than the Location-Only group during acquisition; second, that both would be equally accurate during retention (as in Experiments 1 and 2 when retention came immediately after acquisition), and third, that the Lag group would remain more variable and become more accurate during transfer.

Method

Participants

Twenty undergraduates at Barnard and Columbia College (26 women, 4 men) participated to fulfill an Introductory Psychology class experiment.

Apparatus and Stimuli

Due to incompatibilities between the old program and new computers, the pyramid game was reprogrammed for Experiments 4 and 5. The new display is shown in Figure 5. Points appeared in a box at the upper left corner of the screen. After a path was completed (correct or not), pressing the Up-Arrow key returned the cursor to the top of the pyramid.

Two different size pyramids were used. The 10-pyramid required 10 left and right presses to move the cursor from the top to the bottom. In this size pyramid there are 1,024 different paths. The number of paths to each end-point location (indicated by letters A through K) are shown below:

A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
1	10	45	120	210	252	210	120	45	10	1

The 7-pyramid had the same number of paths and exits as the one used in Experiment 1.

Procedure

Preliminary testing with the new game indicated that its much higher speed necessitated longer acquisition blocks to establish stable variability levels. This is why the size of the initial pyramid was increased and why the number of points earned during each block in acquisition and retention was increased from 25 to 50. As in prior motor studies (e.g., Shea &Morgan, 1979), the number of points earned in transfer was reduced (to 10 per block). The total number of points was 740.

Table 7 presents the sequence of location and lag constraints for both pyramids.

Instructions. The instructions used in Experiment 1 were modified, directing students to return to the large common room whenever a sign on the screen read "time for a break." These were read to participants, who were randomly assigned to one of two groups, Lag or Location-Only.

Acquisition and retention. The Location-Only-practice group earned 100 points for each location constraint during acquisition and retention on the 10-pyramid. The Lag-practice group earned 100 points for each location–lag constraint during acquisition and 100 for the common location-only constraint in retention. After the acquisition phase, a box indicating that it was time for a break appeared on the screen. This break was short, similar to that in Experiment 3, lasting for 5 min.

Delay task. After the retention phase, a box again appeared on the computer screen indicating a break. Participants came to the large common room where they were given red and black felt-tip markers and asked to create patterns/designs in three 8 × 8 grids. This break was longer, lasting for 30 min.[4]

Transfer. At the start of transfer, the 7-pyramid appeared on the screen: 10 points were earned on this pyramid for exiting at the fifth end point from the left (E), followed by 10 points for exiting at E by a path different from two prior paths (ELag2). At this point, the 10-pyramid appeared and 10 points were earned for exiting at the tenth end point from the left (H), followed by 10 points for exiting at H by a path different from one prior path (HLag1). Notice that this end point was neither required nor rewarded during acquisition.

Debriefing. There was no time limitation for earning the 740 points (600, acquisition; 100, retention; 40, transfer). At the end of the experiment, participants were debriefed and asked what they did to earn points and if what they did changed during the experiment.

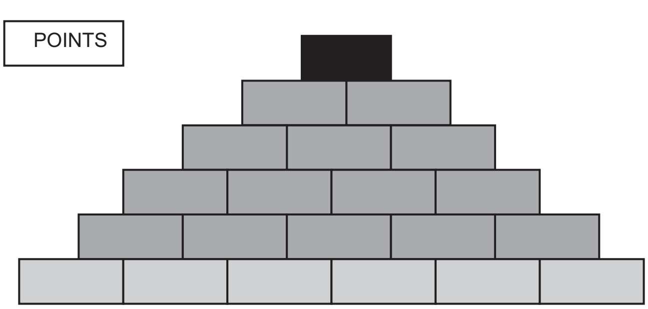

Figure 5. A reconfigured 5-pyramid display similar to the 7- and 10-pyramids used in Experiments 4 and 5. Points appeared in the box so labeled.

Results

Results for acquisition and retention were analyzed in blocks of 25 reinforced trials each; blocks for retention included 10 reinforced trials each. Figure 6 presents mean percentages for both groups during acquisition (Blocks 1–12) and retention (Blocks 13–14) on the 10-pyramid, and during transfer on the 7-pyramid (Blocks 15–16) and the 10-pyramid (Blocks 17–18). Constraint series for each group are found in Table 7.

Variability. During acquisition, the two-way ANOVA for percentage of different paths showed a main effect of group, $F(1, 18) = 22.162$, $p < .01$, $n^2 = .552$, and a Group × Block interaction, $F(11, 8) = 5.341$, $p < .05$, $n^2 = .880$. The Lag group took more different paths than the Location-Only group; the difference increased during acquisition.

To determine if students were aware that all constraints were relaxed during retention, we examined if they switched from the single end point required during the last acquisition block (End Point E). Table 3 shows that, during retention, 90% of the Lag group and 100% of the Location-Only group went to locations different from the one required at the end of acquisition.

During retention, the only significant effect was for group, $F(1, 18) = 14.100$, $p < .01$, $n^2 = .439$. Again, the Lag group generated more different paths than the Location-Only group. Retention refers to sustaining a variability level when the early constraints that generated the level are no longer in effect. The Pearson correlation between the last blocks in acquisition (Block 12) and retention (Block 14) was significant ($r = .583$, $p < .01$), showing that the variability levels had been maintained.

During transfer on the 7-pyramid, there was a main effect of group, $F(1, 18) = 8.455$, $p < .01$, $n^2 = .320$. During transfer on the 10-pyramid, there was also a main effect of group, $F(1, 18) =$

[4] The reason for introducing the long break was related to the increased number of points earned in the new game. During preliminary testing, students said they were exhausted after acquisition and retention. Because fatigue could easily interfere with sensitivity to changes in condition (one of our hypotheses), a 30-minute break with a completely different task was introduced.

Table 7
Block-by-Block Requirements: Experiment 4

	Blocks 1 through 14 (10-Pyramid)													Blocks 15 through 18			
	Acquisition												Retention	Transfer, 7-Pyramid		Transfer, 10-Pyramid	
Group	1	2	3	4	5	6	7	8	9	10	11	12	13/14	15	16	17	18
Location-only	L1	L1	L2	L2	L3	L3	L4	L4	L5	L5	L6	L6	L7				
Lag	L1-V1	L1-V1	L2-V1	L2-V1	L3-V2	L3-V2	L4-V2	L4-V2	L5-V3	L5-V3	L6-V3	L6-V3	L7				
All groups														L6	L6-V2	L9	L9-V1

Note. L = location constraints; V = lag constraints. For values of L1-L7 and V1-V3, see Table 2. L9 is the 4th end point (H) from the right side of the 10-Pyramid.

11.293, $p < .01$, $n^2 = .386$. The Lag group remained more variable than the Location-Only group on both pyramids during transfer.

Accuracy. The two-way ANOVA for percentage of correct paths taken during acquisition showed main effects of block, $F(11, 8) = 15.347$, $p < .01$, $n^2 = .955$, and group, $F(1, 18) = 12.870$, $p < .01$, $n^2 = .417$. As shown in Figure 6, although accuracy levels increased and decreased with constraint changes, they remained lower in the group with the lag requirements.

Accuracy was high in both groups during retention: There were no significant group differences. However, there was a main effect of block, $F(1, 18) = 4.612$, $p < .05$, $n^2 = .204$. Accuracy increased in both groups between Blocks 13 and 14.

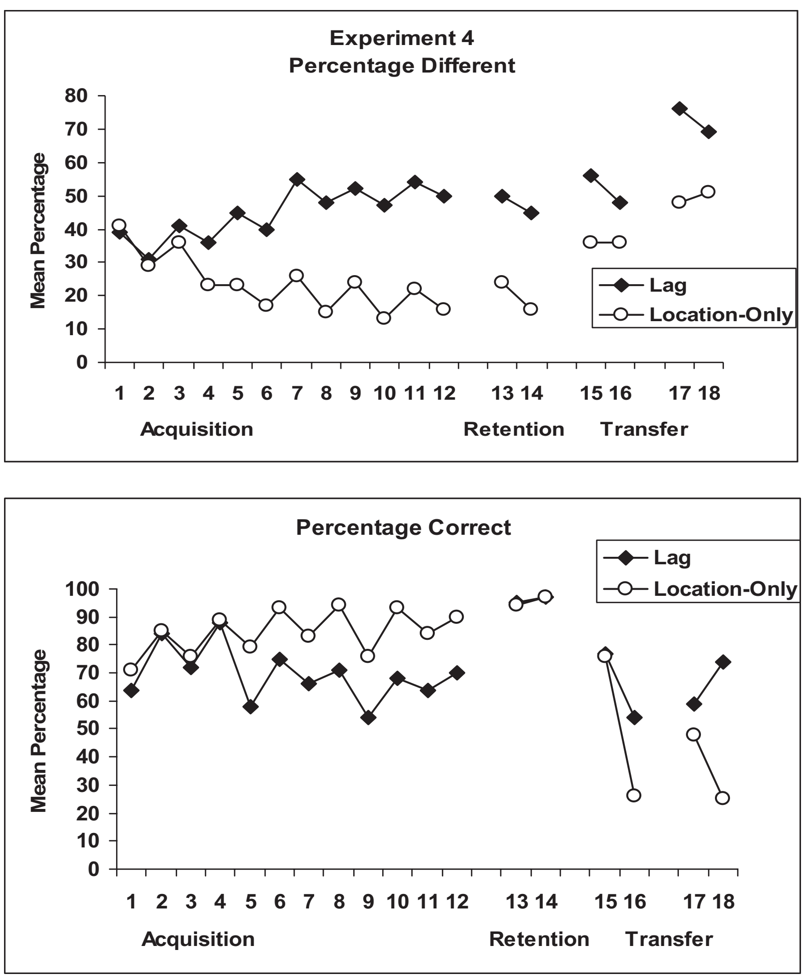

Figure 6. Variability (percentage of different paths) and accuracy (percentage of correct paths) for Lag and Location-Only groups in Experiment 4.

The two-way ANOVA for percentage of correct paths during transfer on the 7-pyramid showed main effects of group, $F(1, 18) = 8.052$, $p < .05$, $n^2 = .309$, and block, $F(1, 18) = 82.679$, $p < .01$, $n^2 = .821$. The Lag group became more accurate than the Location-Only. The interaction (Block × Group) was also significant, $F(1, 18) = 11.627$, $p < .01$, $n^2 = .392$. Although both groups declined in accuracy between Blocks 15 and 16, the decrease in the Location-Only group was greater than in the Lag group.

During transfer on the 10-pyramid, there was a main effect of group, $F(1, 18) = 29.739$, $p < .01$, $n^2 = .623$. The interaction (Block × Group) was also significant, $F(1, 18) = 13.588$, $p < .01$, $n^2 = .430$. Between Blocks 17 and 18, accuracy increased in the Lag group and declined in the Location-Only group.

Optimal period. The earliest acquisition block during which variability was significantly correlated with variability in the last block of retention was Block 5 ($r = .698$ $p < .01$).

Self-Reports. As shown in Table 4, responses in the Lag and Location-Only groups were quite similar: For both, the most frequent response was End Points; both also mentioned Varying Patterns to the Same End Point.

Discussion

As in Experiment 3, we were primarily interested in the effects of learned variability levels on transfer.

Did differences in practice affect variability and accuracy during acquisition? Yes. Variability, measured as percentage of different paths, was higher in the Lag than in the Location-Only group during acquisition. Conversely, accuracy—measured as percentage of correct paths—was higher in the Location-Only group.

Did variability differences affect performance during retention and transfer? Yes. During retention when the location constraint was identical in both groups, the Lag group generated more different paths but was equal in accuracy to the less variable Location-Only group. During transfer, both variability and accuracy were higher in the Lag group.

In sum, all our predictions were correct. Although variability remained higher in the Lag group during acquisition, retention, and transfer, accuracy shifted. It was higher in the Location-Only group during acquisition, equal during retention, and higher in the Variability group during transfer. The retention results replicate those of Experiments 1 and 2, which used the same retention task following directly after acquisition. The transfer results, despite the longer break, replicate those of Experiment 3, supporting the contention that high variability facilitates transfer. To determine if successful transfer depends on earlier mastery of lags (how to vary), Experiment 5 introduced a novel transfer task.

Experiment 5

The novel transfer task in Experiment 5 was also designed to make it possible for the Location-Only group to be equally or more successful than the Lag group at mastering it. It required three alternations between two end points on the smaller, 7-pyramid. The end points were the second (B) and fourth (D) from the left side of the bottom row on the pyramid. The alternation sequence was BDBDBD. One point was earned at each end point.

Two mutually exclusive predictions were made. The Location-Only group could be more successful because repetition (going to the same end point) would not work after one point was earned, indicating that the required location had changed. The Lag group might be less successful because once a point was earned for exiting at a particular location, its members should try different paths to that location. Both results would be based on learning how to do something. Alternatively, if the Lag group was more sensitive to changes in condition (i.e., noticing the pattern of alternating end points), it might become more accurate during transfer than the Location-Only group.

Method

Participants

Twenty undergraduates at Barnard and Columbia College (29 women, 1 man) participated to fulfill an Introductory Psychology class experiment.

Apparatus and Stimuli

The apparatus and stimuli were identical to those in Experiment 4.

Procedure

The number of points earned during blocks in acquisition and retention was 50; 1 point was earned in each transfer block. The total number of points was 706. As in Experiment 4, a half-hour delay was imposed between retention and transfer. During the delay, participants worked on the same task with felt-tip markers as in Experiment 4.

Table 8 presents sequence of location and lag constraints for both pyramids.

Instructions. These were identical to the instructions used in Experiment 4. They were read to participants, who were randomly assigned to one of the two groups.

Acquisition and retention. The Location-Only-practice group earned 100 points for each location constraint during acquisition and retention on the 10-pyramid. The Lag-practice group earned 100 points for each location–lag constraint during acquisition and for the location-only constraint in retention. After the acquisition phase, a box indicating that it was time for a break appeared on the screen. This break was short, lasting for 5 min.

Delay task. After the retention phase, a box again appeared on the computer screen indicating a break. Participants came to the large common room where they were given red and black felt-tip markers and asked to create patterns/designs in three 8 × 8 grids. As in Experiment 4, to counteract fatigue, this break was longer, lasting for 30 min.

Transfer. At the start of transfer, the 7-pyramid appeared on the screen: 6 points were earned on this pyramid, 1 each for alternating between the B and D end points.

Table 8
Block-by-Block Requirements: Experiment 5

	Blocks 1 through 14 (10-Pyramid)													Blocks 15 through 20					
	Acquisition												Retention	Transfer, 7-Pyramid					
Group	1	2	3	4	5	6	7	8	9	10	11	12	13/14	15	16	17	18	19	20
Location-only	L1	L1	L2	L2	L3	L3	L4	L4	L5	L5	L6	L6	L7						
Lag	L1-V1	L1-V1	L2-V1	L2-V1	L3-V2	L3-V2	L4-V2	L4-V2	L5-V3	L5-V3	L6-V3	L6-V3	L7						
All groups														B	D	B	D	B	D

Note. L = location constraints; V = lag constraints. For values of L1-L7 and V1-V3, see Table 2. Location constraints for the 7-Pyramid alternated between the second (B) and fourth (D) end points from the left side.

Debriefing. There was no time limitation for earning the 706 points (600, acquisition; 100, retention; 6, transfer). At the end of the experiment, participants were debriefed and asked what they did to earn points and if it changed during the experiment.

Results

As in Experiments 1 through 4, responding was broken into blocks of 25 reinforced trials. Because these included correct and incorrect response sequences, percentages were calculated for group comparisons.

The top and bottom panels of Figure 7 present mean percentages of different and correct paths on the 10-pyramid during acquisition (Blocks 1–12) and retention (Blocks 13 and 14) and on the 7-pyramid (Blocks 15–20) during transfer.

Variability. During acquisition, the two-way ANOVA for percentage of different paths showed a main effect of group, *F*(1,

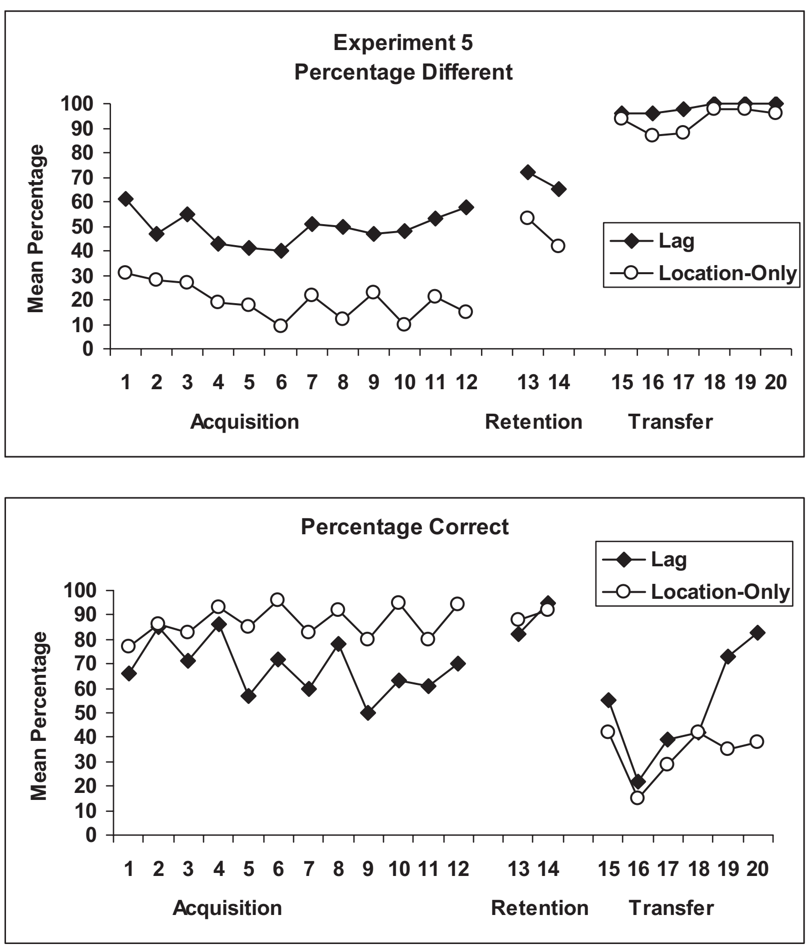

Figure 7. Variability (percentage of different paths) and accuracy (percentage of correct paths) for Lag and Location-Only groups in Experiment 5.

18) = 20.978, $p < .01$, $n^2 = .538$, and a Group × Block interaction, $F(11, 8) = 4.952$, $p < .05$, $n^2 = .872$. The Lag group took more different paths than the Location-Only group; the difference increased during acquisition.

To determine if students were aware that the constraints were relaxed during retention, we examined if they exited the pyramid at locations other than the single end point required during the last acquisition block (End Point E). As shown in Table 3, 100% in each group did so during the two retention blocks.

During retention, there was a main effect of group, $F(1, 18) = 4.536$, $p < .05$, $n^2 = .201$. The Lag group continued to take more different paths than the Location-Only group. A Pearson correlation between the last blocks in acquisition (Block 12) and retention (Block 14) was significant ($r = .698$, $p < .01$).

During transfer, there were main effects of block, $F(5, 14) = 3.025$, $p < .05$, $n^2 = .519$, and group, $F(1, 18) = 6.534$, $p < .05$, $n^2 = .266$. Variability increased during transfer. The Lag group took more different paths than the Location-Only group.

Accuracy. The two-way ANOVA for percentage of correct paths taken during acquisition showed main effects of block, $F(11, 8) = 11.521$, $p < .01$, $n^2 = .941$, and group, $F(1, 18) = 49.405$, $p < .01$, $n^2 = .733$. As shown in Figure 7, accuracy levels shifted with changes in constraints; they were lower overall in the Lag group.

Accuracy was high in both groups during retention: There was no significant group difference. However, there was a significant effect of block, $F(1, 18) = 4.932$, $p < .05$, $n^2 = .215$. Both groups increased in accuracy between Blocks 13 and 14.

The two-way ANOVA for percentage of correct paths during transfer on the 7-pyramid showed main effects of group, $F(1, 18) = 12.547$, $p < .01$, $n^2 = .411$, and block, $F(5, 14) = 13.912$, $p < .01$, $n^2 = .832$. Accuracy both decreased and increased between Blocks 15 and 20. As shown in Figure 7, the Lag group became noticeably more accurate by the end of transfer.

Optimal period. The Pearson correlation run between percentage of different paths during Block 3 of acquisition, the first constraint change for both groups, and Block 14, end of retention, showed that early variability was positively related to later variability ($r = .520$, $p < .05$).

Self-Reports. As shown in Table 4, the majority of responses for the Lag group occurred in the category Vary Patterns to the Same End Point; all those of the Location-Only group appear under End Points.

Discussion

As in Experiments 3 and 4, we were primarily interested in the effects of learned variability levels on transfer to novel problems.

Did differences in practice affect variability and accuracy during acquisition? Yes. Variability, measured as percentage of different paths, was higher in the Lag than in the Location-Only group during acquisition. Conversely, accuracy—measured as percentage of correct paths—was higher in the Location-Only group.

Did variability differences affect performance during retention and transfer? Yes. During retention, the Lag group generated more different paths but was equal in accuracy to the less variable Location-Only group. During transfer, both variability and accuracy were higher in the Lag group.

Did early mastery of a specific task facilitate transfer? No. Unlike Experiment 3 and 4, in which the transfer task involved lags, the task here was completely new to both groups. Thus, high variability appears to have facilitated transfer to the novel task because the Lag group had become sensitive to changes in contingency, not because it had already mastered an earlier version of the task.

General Discussion

The present set of experiments examined the effects of practice on variability (Experiments 1 and 2), and the effects of variability on transfer (Experiments 3, 4 and 5). The basic task involved sequences of left–right presses (paths) from the apex to the base of three pyramidal displays requiring 5, 7, or 10 right–left key presses (5-, 7-, and 10-pyramids). Percentage of different paths was our measure of variability; percentage of correct paths, our measure of accuracy.

Findings

Effects of Practice on Variability

Experiments 1, 2, and 3 replicated prior work showing that early constraints that require high variability sustain higher variability levels than early constraints that can be mastered without high variability. They extended this work by introducing Alternating practice and a variant, Extended practice. In both, students mastered a location constraint before exposure to a combined location–lag constraint. In Alternating practice, the successive constraints were novel; in Extended practice, three pairs (location and combined location–lag) were repeated. Total number of switches between constraints was the same.

Alternating and Extended practice differed from earlier motor studies in the number of switches between less and more variable constraints. For example, compared to the current 11 switches between location and location–lag constraints, Carlson and Yaure (1990) included only 1, between less (Blocked) and more (Random) variable practice conditions. Likewise, Lai et al., (2000) included 1, between less (Constant) and more variable (Variable) practice conditions. The results also differed. During transfer (Experiment 3), the Alternating-practice group sustained variability and accuracy levels comparable to those of Lag-practice group and higher than that of the Location-Only-practice group. In Carlson and Yaure (1990), there were no between-group differences on subsequent problem solving. In Lai et al. (2000), Consistent-Variable practice was more effective than Variable-Consistent or Variable-Variable. We suggest that the divergence in results stems from degree of difficulty faced early in training. Recall that in the learned-variability model, only variability levels associated with early mastery are maintained. The initial constraints for our Lag group were far less stringent than those in the two earlier studies; ours required variability but allowed for mastery (the initial lag was only 1).

In all three experiments, an early Optimal Period was identified in which early variability levels were positively correlated with later ones.[5] In accord with the learned-variability model, our assumption is that problem representations and default rules/strategies that generate and maintain habitual variability levels are acquired during this period.

Effects of Variability on Transfer

Experiments 3, 4, and 5 expanded prior work on learned variability by showing that high habitual levels of variability facilitate transfer. At issue here is the content of the learning that generated and sustained the high variability that, in turn, enhanced transfer. Two possibilities were examined: learning how to vary and learning when to vary. As discussed earlier, "how" involves specific responses,[6] as well as generating exception rules or shifting parameters of a generalized motor program. "When" involves noticing if changed conditions make variation necessary.

In Experiments 3 and 4, the transfer task was similar to Alternating practice: Students first had to exit the pyramid by a specific end point before varying paths to that end point. Groups that mastered lag constraints were more successful than the Location-Only groups during transfer, indicating that—at least with this task—transfer depended on learning how to vary, that is, in a specific way.

However, the transfer task in Experiment 5 (repeated and immediate alternation between two different end points) was new to both Lag and Location-Only groups. In this case, the most plausible explanation for greater accuracy in the high variability group was noticing that the contingency had changed. In other words, despite the fact that nobody could say what they did to earn points on the final pyramid, the Lag group had learned when to vary.

Hypotheses

The results of Experiments 3 and 4 (where the transfer tasks included lags) support the hypothesis of schema theory (Schmidt, 1975; Wulf & Schmidt, 1988) that variability practice affects transfer to the degree that the transfer task is a variant of the generalized motor program acquired during acquisition. Here, the successful Lag and Alternating groups had already learned to take different paths to particular end points.

However, the transfer task in Experiment 5 (alternating between two end points) was not a variant of a location–lag task practiced earlier. Yet the Lag group also outperformed the Location-Only group, which had practiced switching between end points (albeit after 50 successful trials rather than just 1 and not back and forth between two end points). This result accords with hypotheses from the learning and cognitive literatures. Chase and colleagues (Joyce & Chase, 1990; Mayfield & Chase, 2002) argued that high variability facilitates transfer because it sensitizes learners to changes in conditions. In a 1988 talk at Columbia, Simon pointed out that learning from worked-out examples depends on acquiring a "habit of noticing and acting on noticing." One learns what to notice and what to do when the noticing occurs. Doane et al. (1996) reasoned that (more variable) exhaustive feature-comparison strategies increase observer sensitivity relative to (less variable) global-comparison strategies.

The result is also consistent with Lai et al.'s (2000) contention that the critical element in variable practice is when variability is introduced and not how closely practice matches transfer and suggests that reconstruction (Lee & Magill, 1983) is a consequence of sensitivity: Exception rules are constructed and parameter shifts occur when changed conditions are noticed.

We contend that the mechanism by which such sensitivities are acquired is identical to that discussed earlier, operant conditioning. All aspects of responding that are associated with success increase in frequency; those associated with early success become part of default rules. Like levels of variability, levels of sensitivity associated with mastery are maintained. The current results suggest why: Connections between perception and performance may be critical for mastering the variability constraints. To be variable and accurate requires noticing two things: When a contingency changes and how one has recently responded (for example, which paths to a specific end point were recently taken).

This idea expands and amends learned-variability theory. We previously hypothesized that skill acquisition involves learning how to do something (the skill) and how differently to do it (the variability level). Constraints encountered early in acquisition and difficulties in mastering them determine default rules, strategies that generate the basic skilled response and the variability level it sustains. Exception rules related to their defaults are acquired when conditions change. We amend the theory by adding that learning also involves when to alter a skill; high variability increases sensitivity to changed conditions, thus activating or facilitating acquisition of exception rules or, in motor terms, parameter shifts.

Conclusions

To fully understand the effects of variability on learning, three things must be understood. Why is it advantageous to be variable? When is it advantageous to be variable? What makes variability advantageous?

Prior work has answered the first two questions. High variability facilitates skill acquisition (Siegler, 1996; Stokes, 1995), retention (Proteau et al., 1994; Shea, Kohl, & Indermill, 1990), and transfer (Carlson & Yaure, 1990; Schmidt & Bjork, 1992). It is advantageous to be highly variable early in skill acquisition, assuming that the variability levels support mastery and, as a result, are maintained (Stokes & Balsam, 2001). The current study supports earlier suggestions (Doane et al., 1996; Mayfield & Chase, 2002) that an important advantage of high variability is perceptual and involves increased sensitivity to changed conditions, the consequence of which is activation of appropriate existing strategies/schema or construction of variants thereof.

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[5] In Experiment 2, alternative explanations (novel constraints, anticipated intermittent lags) for sustained high variability in the Alternating and Extended groups were examined and rejected.

[6] Debriefing showed that students learned how to respond during acquisition. Overall, the most frequent strategy in the groups exposed to lag constraints (Lag, Alternating, and Extended) was some version of "varying paths to a specific end point." Some students also described how they did this, for example, by mirroring or reversing paths. In Experiment 5, 60% of the Lag group mentioned this strategy. The most frequent strategy in the Location-Only groups was some version of "going to a specific end point." In Experiment 5, everyone (100%) in the Location-Only group said they used this strategy.

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