

The influences of guiding cues on motor skill autonomy in rats

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Abstract How does the effectiveness of guiding cues influence the development of motor skill autonomy? We utilized two sets of guiding cues (lights vs. reversed-lights conditions) that differed in their effectiveness to control a left–right leverpress sequence in rats. We separately measured the development of stimulus control by panel lights on guiding-cues trials and the development of stimulus control by practice cues on no-cue probe trials within the same sessions. Accuracy in the presence of the guiding cues was acquired faster in the lights condition than in the reversed-lights condition, but subjects in the reversed-lights condition were more able to complete the skill autonomously than those in the lights condition. Throughout acquisition, control by guiding cues and practice cues developed at the same rate in the reversed-lights condition, but control by practice cues (autonomy) developed at a slower rate than did control by guiding cues in the lights condition. At the end of training, subjects that had been exposed to the reversed-lights condition displayed higher levels of autonomy than did those exposed to the lights condition. The less effective guiding cue (reversed-lights) produced greater levels of autonomy than did the more effective cue (lights), even though control by this guiding cue developed more slowly. Thus, guiding your child by the hand too much may reduce his or her ability to complete the task independently. We discuss the similarity to prompt dependence in children with learning disabilities and transfer of stimulus control.

Keywords Autonomy · Expertise · Motor skill · Prompt dependence · Skill learning · Stimulus control · Rats

Motor skill learning plays essential roles in educational systems, sports, arts, factories, and military training. As a result, cognitive scientists and human factors psychologists have focused extensively on motor skill learning and the development of expertise in humans. Many models have been proposed, ranging from stage models of skill learning and automaticity (e.g., Fitts & Posner, 1967) to models of cognitive architectures, evolving in complexity from the power law of practice (Newell & Rosenbloom, 1981; Rosenbloom, 2006), to SOAR as a unified theory of cognition (Laird, 1986; Newell, 1990; Rosenbloom, Laird, & Newell, 1989), to ACT-R (Anderson & Lebiere, 1998). Turning to nonhumans, Helton (2004, 2007a, 2007b) recently focused on modeling skill learning and expertise in canines involved in competitive agility training. He concluded that his dogs' skill learning fit nicely with Fitts and Posner's three-stage model of expertise development. Nevertheless, researchers debate whether one should classify dog training by the cognitive mechanisms assumed to exist in human models, such as divided attention and "deliberate practice." While these models are important to human learning, they may not represent the simpler mechanisms of motor skill learning inherent in nonhumans. After all, even rats have been demonstrated to learn skills involved in basketball (Reid, 2010) and in the detection of landmines, narcotics, and tuberculosis (Lambert, 2011). This study focuses on improved understanding of these simpler mechanisms, which we hope may be applicable to children with learning disabilities.

Motor skill learning in humans typically depends upon early guidance by an instructor, followed by extensive practice. This eventually results in the ability to complete the task autonomously. Much research has focused on the behavioral consequences allowing trial-and-error learning. Nevertheless, these situations also involve antecedent stimuli that provide information about the appropriate action to take. Children with autism or severe learning disabilities often fail to learn to produce these skills independently, without continued

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prompts provided by the instructor. *Prompt dependence* describes the failure of stimulus control to switch from the teacher's prompt (now say "Thank you") to control by situational cues (receiving a gift). MacDuff, Krantz, and McClannahan (2001) argued persuasively that "teachers must use teaching procedures that are likely to bring the target response under the control of environmental stimuli rather than prompts from other people" (p. 45). They provided a helpful review of those procedures and when they should be used. However, foundational research about changes in stimulus control and cue interaction during skill learning should lead to deeper understanding of the mechanisms of skill learning and the causes of prompt dependence.

The present study with rats focuses on these antecedent stimuli in their roles as guiding cues that come to control behavior patterns during motor skill learning. Recent research in this lab (e.g., Reid, Nill, & Getz, 2010) emphasized how skill learning in rats requires a change in stimulus control. At least two sources of stimulus control are involved: environmental events from instructors or lights in a Skinner box and *practice cues* that result from the subject's own behavior of repeating the same response pattern (Lattal, 1975; Shimp, 1981, 1982). As the skill is acquired, reliance on (or control by) environmental guiding cues decreases until the behavior pattern can be performed correctly and efficiently in the absence of those guiding cues—the autonomous skill now controlled by newly developed practice cues.

Reid, Rapport, and Le (2013) demonstrated that two similar procedures of manipulating panel lights as guiding cues for a left–right (L–R) leverpress sequence (the skill to be acquired) differed dramatically in their effectiveness as controlling stimuli. In the lights condition, the onset of panel lights corresponded to the left or right lever to be pressed (On = S+, Off = S–), and skill learning was rapid. The reversed-lights condition simply reversed the order of presentation of the two panel lights, without changing the L–R response requirements, such that the absence of illumination of panel lights corresponded to the left or right lever to be pressed (Off = S+, On = S–). Skill learning was delayed considerably, requiring twice the number of sessions. Their series of experiments demonstrated that the differences in the effectiveness of these two guiding-cue conditions were strong and reliable.

The purpose of the present study was to determine whether the speed of development of behavioral autonomy for a motor skill is influenced by the effectiveness of environmental guiding cues. Accuracy may always be high if you "lead the child by the hand" as the task is completed, but such direct guidance may not lead to faster autonomy. Prompt dependence may reflect this failure for the task to become controlled adequately by other cues.

Following the experiments with rats by Reid and his colleagues, we used the same L–R response sequence as the skill

to be acquired. We also used the same lights and reversed-lights conditions because of their confirmed differences in effectiveness as guiding cues. The experiment was designed to compare the learning rates of the response sequence (measuring L–R accuracy) in the presence of guiding cues and in their absence (autonomy) during probe trials in the same sessions, without changing the response requirements. We predicted that the lights condition would produce rapid learning and high accuracy in the presence of those guiding cues but that accuracy would be lower during probe trials that measured the development of behavioral autonomy. We predicted that the less effective reversed-lights condition would produce slower learning but that the development of behavioral autonomy would be more rapid than in the lights condition.

We assumed that sequence accuracy during probe trials would reflect the development of stimulus control by practice cues that develop from the subject's repeated behavior pattern across sessions. More behavioral history completing the sequence would lead to greater autonomy, which we define as the acquired ability to complete the sequence correctly without the lights as cues, such as during probe trials. Thus, our dependent variables separately measured the dynamics of stimulus control by panel lights as guiding cues and the dynamics of stimulus control by practice cues in the same sessions, as accuracy improved across the sessions of the experiment.

Method

Subjects

Twenty naïve 4-month-old Long Evans female rats were housed in individual polycarbonate cages in an animal facility that maintained constant temperature and humidity and a 12:12-h light:dark cycle. We maintained each subject at approximately 80% of its free-feeding body weight by providing supplemental food after each daily session. Water was freely available in the home cages.

Apparatus

The experiment utilized four standard Med Associates modular test chambers for rats measuring 30 × 24 × 22 cm. Each chamber was located inside an isolation chamber containing a ventilation fan, one 7-watt 120-V nightlight, and a miniature closed-circuit TV camera on the ceiling. A sound generator produced constant white noise at approximately 65 db. Each operant chamber contained two retractable levers on the front wall and two nonretractable levers on the rear wall. Each pair of levers was separated by 16.5 cm center to center and located 6 cm above the floor. The magazine hopper, 5 × 5 cm, was

centered between the two response levers on the front wall, 3 cm above the floor. One round 28-V white stimulus lamp, 2.5 cm in diameter, was located 2.5 cm above each of the four levers, and a 28-V houselight (GE1819) was located at the center top of the rear wall. The Med Associates pellet dispenser dispensed 45-mg Research Diet (Formula A/1) pellets. All four operant chambers were controlled by a single Dell personal computer (Pentium 4) located in an adjacent room and programmed in MED-PC IV, which controlled all experimental conditions and recorded every event and its time of occurrence with 10-ms resolution.

Procedure

We randomly assigned the 20 rats to four groups in a 2 (condition: lights, reversed lights) \times 2 (probe type: both lights, no lights) factorial design. One group was exposed to the lights condition combined with no-lights probe trials (abbreviated L–NL). A second group was exposed to the lights condition combined with both-lights probe trials (abbreviated L–BL). Two groups were exposed to the reversed-lights condition, one with no-lights probes (RL–NL) and one with both-lights probes (RL–BL). The details of these conditions are described below. We measured two dependent variables: the accuracy of completing correct L–R leverpress sequences controlled by panel lights as guiding cues and L–R leverpress accuracy during probe trials when the panel lights provided no differential information to control response selection. Thus, our dependent variables separately measured the dynamics of stimulus control by panel lights as guiding cues and the dynamics of stimulus control by practice cues in the same sessions, as accuracy improved across 36 sessions.

Training

Leverpress training occurred on the right lever on the front wall of the apparatus. The panel light over that lever was illuminated (S⁺) for the lights groups, while the other panel lights were off (S[–]). These lights were reversed for the two reversed-lights groups: off (S⁺) over the corresponding lever and illuminated (S[–]) for the incorrect levers. Leverpress training occurred until the subject earned 45 pellets on a continuous reinforcement schedule in three consecutive sessions. By providing food for pressing the right lever and no food for pressing the left lever, an unintended preference for the right lever could develop that might influence the frequencies of two-response sequences in subsequent conditions. Therefore, in the second training condition, the levers on the front wall were retracted and unavailable, and the two levers and panel lights on the rear wall (opposite to the food hopper) were used for all remaining procedures. The second training condition reinforced pressing both levers in any order on the rear wall. This condition delivered a food pellet for each switch from left

to right or right to left, without regard to perseveration on a lever. For example, the following sequences would produce food delivery: LR, RL, LLR, RRRRRL, and so forth. A 50-ms tone accompanied pellet delivery. The two panel lights remained on, but briefly pulsed off (50 ms) for each leverpress for subjects in the two lights groups and off (pulsing on) for the two reversed-lights groups. No timeouts occurred during this free-operant procedure. This training condition ended when the subject earned all 45 pellets available for five consecutive sessions.

Experimental procedures

All experimental procedures were composed of discrete trials in which pellet delivery was contingent upon the same L–R leverpress sequence on the rear wall. A 50-ms tone accompanied pellet delivery, followed by a 1-s intertrial interval (ITI). All other sequences resulted in a 3-s time-out. During the ITI and time-out, panel lights and the houselight were off (the nightlight continued to provide general illumination in the isolation chamber), and leverpresses had no programmed consequences. Trials were signaled by the presence of the houselight, whether the preceding trial ended with food delivery or time-out. Sessions lasted for the earlier of 45 min or until 45 pellets were delivered.

Guiding-cues trials

The lights and the reversed-lights conditions manipulated the panel lights as guiding cues. At the beginning of each trial in the lights condition, the panel light above the left lever was on, while the panel light above the right lever was off. A press to either lever caused the left panel lamp to turn off and the right lamp to be illuminated. A second leverpress ended the trial, turning off both panel lamps and delivering a food pellet or beginning the 3-s time-out. Only L–R leverpress sequences produced food. No feedback about response accuracy was provided until two leverpresses were completed. The onset and offset of panel lights were exactly reversed for the reversed-lights condition.

Probe trials

Two types of probe trials eliminated the information value of the two panel lights without changing the response requirements. Pellet delivery was still contingent upon the same L–R leverpress sequence. On no-lights probe trials, neither panel light was turned on during the trial, but leverpresses pulsed on the corresponding light briefly (50 ms) as feedback that the lever had been pressed. On both-light probe trials, both panel lights were illuminated during the trial, but leverpresses pulsed off the corresponding light briefly.

Sessions

We created three types of sessions. Guiding-cue sessions consisted completely of trials containing the same type of guiding cues (either lights or reversed lights). Probe sessions consisted of trials with the same guiding cues but where every fifth trial was a probe trial on which guiding cues were removed (no lights or both lights). The third type of session, all-probe sessions, was composed entirely of no-lights probe trials or both-light probe trials without any guiding-cue trials. The response-reinforcement contingencies were identical in all three types of sessions.

The experiment alternated guiding-cue and probe sessions for 36 sessions, yielding 18 sessions of each type. This procedure allowed the separate measurement of improving L–R sequence accuracy in the presence and absence of guiding cues, as subjects acquired the L–R sequence over 36 sessions. Guiding-cue sessions measured the influence of guiding cues on sequence accuracy without the influence of probe trials. Probe sessions measured the influence of practice cues on sequence accuracy during the probe trials, but also measured the influence of guiding cues on sequence accuracy during guided-cue trials. By alternating the two types of sessions, we could assess potential interference of probe trials during probe sessions. Following this block of 36 sessions, we exposed all subjects to 5 all-probe sessions to measure their acquired ability to complete the L–R sequence autonomously.

Our dependent variables separately measured the dynamics of stimulus control by (1) panel lights as guiding cues and (2) practice cues, in the same sessions as accuracy improved across 36 sessions. The final all-probe sessions allowed us to measure whether the more difficult reversed-lights condition would lead to greater autonomy than the lights condition over the course of the experiment.

Results

This experiment investigated how the effectiveness of guiding cues influences the development of motor skill autonomy. Figure 1 compares the acquisition rates of the L–R leverpress sequence when panel lights served as guiding cues for the four groups across all 36 sessions of the experiment. This figure shows accuracy during guiding-cue trials only (disregarding probe trials), despite whether the session also contained probe trials. A 4 (groups) \times 36 (sessions) mixed ANOVA compared accuracy for the four groups across sessions. Naturally, there was a main effect of session as accuracy improved across sessions, $F(35, 525) = 39.72, p < .001, \eta_p^2 = .726$. There was a main effect of group, $F(3, 15) = 5.217, p = .011, \eta_p^2 = .511$, and a sessions \times group interaction, $F(105, 525) = 1.60, p < .001, \eta_p^2 = .242$. As can be seen in the figure, accuracy was systematically lower for the RL–NL group, which represents

the main effect of group. The interaction can be observed in the RL–BL group, whose accuracy began as low as that of the RL–NL group but increased rapidly in session 13 to equal the high accuracies observed in the two lights groups. As was expected, early learning rates (in the first 12 sessions) were higher for the two lights groups than for the two reversed-lights groups.

Figure 2 shows the learning curves in probe trials when the panel lights provided no information. Thus, these curves reflect degrees of autonomy resulting from the development of practice cues as the L–R leverpress pattern occurred repeatedly within and across sessions. A 4 (groups) \times 18 (sessions) mixed ANOVA compared accuracy for the four groups across the sessions containing probe trials. Naturally, there was a main effect of session as accuracy improved across sessions, $F(17, 255) = 16.879, p < .001, \eta_p^2 = .529$. There was no main effect of group, $F(3, 15) = 1.11, p = .376$. However, there was a group \times sessions interaction, $F(51, 255) = 1.507, p = .022, \eta_p^2 = .232$. This interaction can be observed in Fig. 2 by the RL–BL group whose accuracy began very low but reached the highest levels of any group. We predicted that both reversed-lights groups would develop higher levels of autonomy than the lights groups, but this was observed only for the RL–BL group.

The previous figures separately depicted the learning curves when guiding cues were present (Fig. 1) versus absent (Fig. 2). Figure 3 allows a more detailed comparison of learning rates under the two types of stimulus control. It also assesses the influence of the two types of probe trials. The curves with filled symbols display the group averages when panel lights were provided as guiding cues. These curves were also depicted in Fig. 1. The vertical bars display the L–R accuracy during the probe trials, inserted into every other session. These curves were also depicted in Fig. 2. The top panels represent the two lights groups, and the bottom panels represent the two reversed-lights groups. The panels on the right represent the probe condition in which the status of the panel light (on or off) was the same as it had been during the guiding-cues trials; the panel lights were consistent between the guiding-cues trials and the probe trials. For example, for the L–BL group (top right panel), light ON was always S+ for the lights group during guiding-cues trials, and the panel lights were ON during probe trials. Similarly for the bottom right panel, light OFF was always S+ for the reversed-lights group during guiding-cues trials, and the panel lights were OFF during probe trials. The two left panels represent the groups in which the status of the lights during probe trials had always been S– during the guiding-cues trials. Panel lights during these probe trials were inconsistent with those provided during guiding-cues trials.

Figure 3 allows us to assess whether stimulus control by practice cues developed at the same or a slower rate as stimulus control by the panel lights. It also allows us to compare

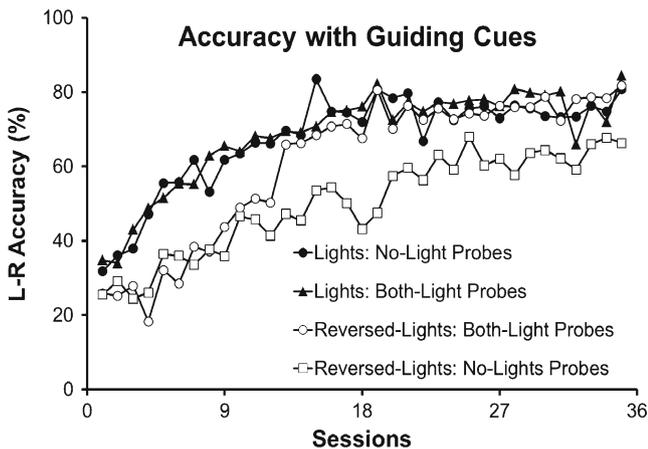


Fig. 1 Mean left–right (L–R) leverpress accuracy (in percentages) across all sessions for the four groups of rats measured on trials on which panel lights were manipulated as guiding cues. Acquisition was faster in the two lights conditions (filled symbols) than in the two reversed-lights conditions (empty symbols). Even though accuracy in both reversed-lights groups began lower than in the lights groups, accuracy in the reversed-lights–both lights group increased abruptly around session 13 to equal that in the lights groups

sessions with and without probe trials to see whether the addition of probe trials in every other session interfered with accuracy during sessions containing only guiding-cues trials. All four panels show that guiding-cues accuracy was the same during sessions with and without probe trials. Accuracy during guiding-cues trials was not influenced by the presence of probe trials; thus, our two measures of accuracy (during probe trials and during guiding-cue trials) were orthogonal. We predicted that the reversed-lights condition would allow faster development of practice cues (i.e., autonomy) than would the easier lights condition. As the bottom panels depict, L–R

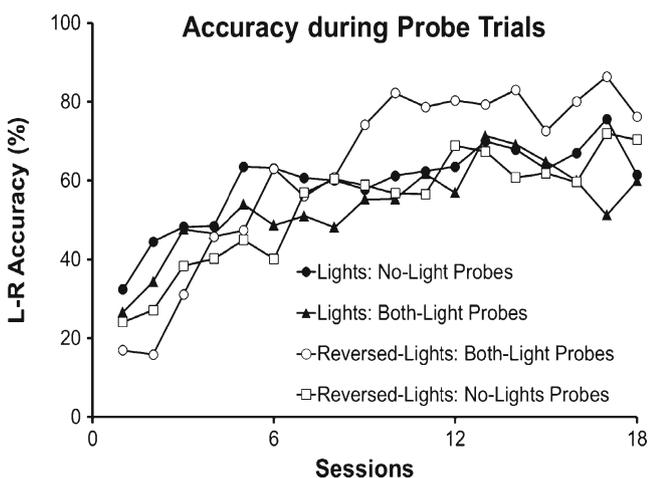


Fig. 2 Mean left–right (L–R) leverpress accuracy (in percentages) for the four groups of rats measured on probe trials on which the panel lights provided no information to influence response selection. Note that accuracy for the reversed-lights–both-lights group began lowest but quickly increased to exceed that of the other groups

accuracy during guiding-cue trials and during probe trials for the two reversed-lights groups developed at approximately the same rate; the heights of the guiding-cues curve and the probe histograms closely matched each other across the 36 sessions. However, the lights groups showed a different pattern. The guiding-cues curves appeared to be reliably higher than the probe histograms, implying that control by practice cues (thus, autonomy) developed at a slower rate than did control by panel lights.

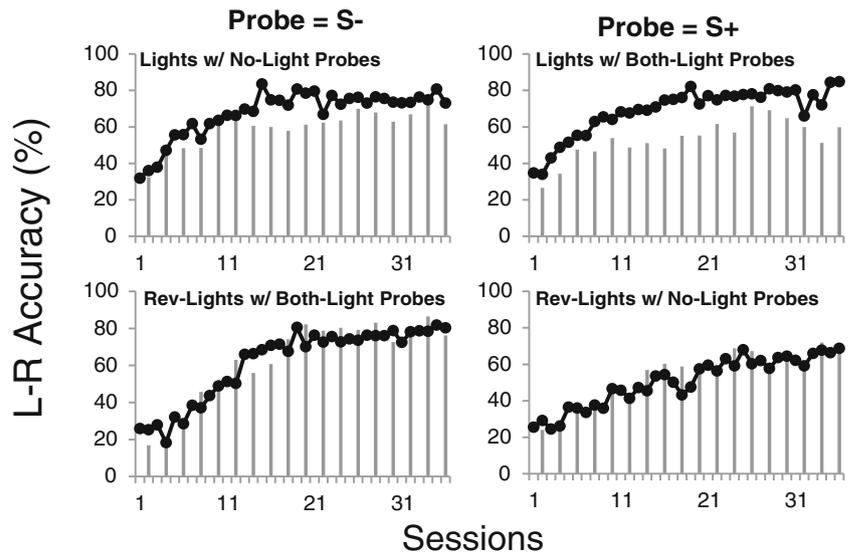
Figure 4 provides a more detailed examination of this difference in developing stimulus control by practice cues and guiding cues. Each of the points in the four panels was calculated by subtracting the L–R accuracy observed during the probe trials from the (generally higher) accuracy observed during the guiding-cues trials. Since 18 sessions contained both guiding-cues trials and probe trials, 18 points are displayed for each group. Positive values were obtained when accuracy during guiding-cues trials exceeded accuracy during the probe trials in the same sessions. A value of zero would represent no difference in accuracy. Negative values represent higher accuracy during probe trials than during guiding-cue trials. The values for both lights groups (top panels) were nearly always positive, so accuracy was less during probe trials than during guiding-cues trials. This effect was not observed for either of the reversed-lights groups (bottom panels), in which the more negative values imply that accuracy during probe trials actually exceeded that during guiding-cues trials.

In order to evaluate group differences, we carried out a group (4) \times probe sessions (18) mixed ANOVA on the differences in accuracy between the guiding-cues trials and the probe trials. There was a main effect of group, $F(3, 15) = 7.948, p = .002, \eta_p^2 = .614$, observed power = .961. There was no effect of probe session and no interaction. Post hoc tests (Tukey HSD with Bonferroni adjustments for multiple comparisons) showed that the L–BL group produced significantly greater differences in accuracy between the guiding-cues trials and the probe trials than did the RL–NL group, $p = .004$, and greater than the RL–BL group, $p = .005$.

Similarly, the L–NL group produced greater differences in accuracy between the guiding-cues trials and the probe trials than did the RL–NL group, $p = .046$, and comparison with the RL–BL group approached statistical significance, $p = .066$. In every comparison, accuracy during probe trials in lights groups was retarded, as compared with guiding-cues trials, whereas it was not for either reversed-lights group.

Figure 5 provides another direct measure of the development of autonomy during the lights and reversed-lights conditions. Following the 36 sessions reflected in previous figures, the rats underwent 5 all-probes sessions. They were designed to measure the degree of autonomy that had developed in each group after 36 sessions of exposure to the previous conditions. An independent-samples t -test demonstrated that the mean

Fig. 3 The four panels provide a comparison of the learning rates under the two types of stimulus control along with the influence of the two types of probe trials. Curves with filled symbols display the mean accuracy for each group when panel lights were provided as guiding cues. The vertical bars display the mean accuracy for each group during probe trials, which were inserted into every other session



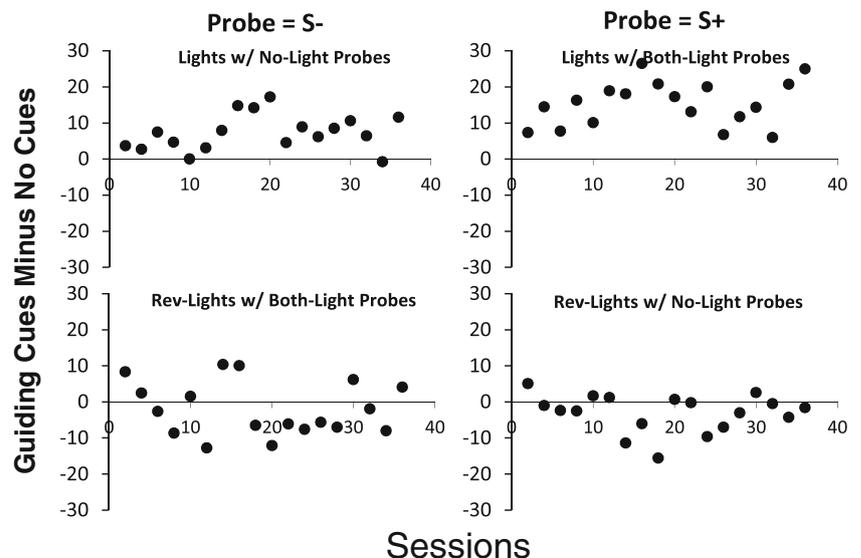
accuracy in the reversed-lights groups was significantly greater during the all-probes sessions (greater autonomy) than in the lights groups, $t(18) = 2.42, p = .013, r^2 = .246$.

Discussion

The purpose of the present study was to determine whether the speed of development of behavioral autonomy for a motor skill is influenced by the effectiveness of environmental guiding cues. We utilized two sets of guiding cues (lights vs. reversed-lights conditions) that had been clearly demonstrated to differ in their effectiveness in controlling the same L–R leverpress sequence reinforced in this study (Reid, Rapport, & Le, 2013). Accuracy in the presence of the guiding cues was

acquired faster in the “easier” lights condition than in the “difficult” reversed-lights condition. Nevertheless, once the guiding cues were no longer available, subjects in the reversed-lights condition were better able to complete the L–R sequence autonomously than those in the lights condition. Throughout acquisition, subjects in the reversed-lights condition produced accuracy levels during probe trials that were equivalent to accuracy levels during guiding-cues trials, indicating that control by guiding cues and practice cues developed at the same rate. However, for subjects in the lights condition, accuracy during probe trials was retarded, as compared with guiding-cues trials, indicating that control by practice cues developed at a slower rate than did control by guiding cues. Finally, once all guiding cues were eliminated at the end of training, subjects that had been exposed to the

Fig. 4 Points represent the difference in development of stimulus control by guiding cues (the panel lights) and practice cues (during probe trials). Positive values were obtained when mean accuracy during guiding-cues trials exceeded accuracy during the probe trials in the same sessions. A value of zero would represent no difference in accuracy. Negative values represent higher accuracy during probe trials than during guiding-cues trials



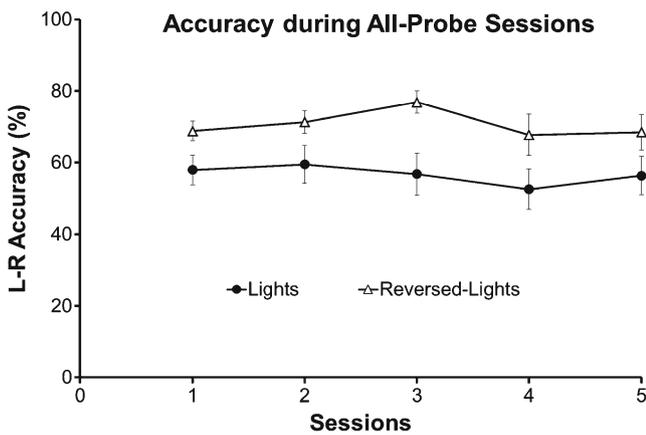


Fig. 5 The two curves show the mean left–right (L–R) accuracy across the five sessions containing only probe trials at the end of experiment. Filled circles represent the means of all subjects in the two lights groups. Open triangles represent the means for the two reversed-lights groups. Error bars represent *SEM*

reversed-lights condition displayed higher levels of autonomy than did those exposed to the lights condition. The less effective guiding cue (reversed lights) produced greater levels of autonomy than did the more effective cue (lights), even though control by this guiding cue developed more slowly. An intuitive application of this finding is that guiding your child by the hand too much may reduce his or her ability to complete the task independently.

This finding is reminiscent of other paradoxical observations in the learning literature. In this case, acquisition rate of autonomous skilled performance was faster after less effective guiding cues. In a related study with pigeons, Reid, Folks, and Hardy (2013) demonstrated that a more difficult two-response simultaneous chain (requiring knowledge of serial order) led to faster autonomy of an L–R key-peck sequence than did a simple follow-red condition. Other dissociations between acquisition rate and long-term retention have been observed with the partial reinforcement extinction effect (Pear, 2001) and with rate sensitivity in habituation (e.g., Davis, 1970; Groves & Thompson, 1970; Peeke & Petrinovich, 1984; Staddon, 1993, 2001). Reid, Rapport, and Le (2013) carefully evaluated feature-positive discrimination bias and spatial S–R compatibility as potential explanations of the numerous observations of transfer of stimulus control in our procedures. However, we have not identified any common behavioral mechanisms that might explain the similarities in these various paradoxical observations.

Nevertheless, the observation that the “difficult” guiding-cue condition produced greater levels of autonomy than did the “easy” condition is consistent with several explanations of human learning in the cognitive psychology literature, where most studies of skill learning are found. However, the differences in terminology and procedures make the relevance of this research to lower animals questionable. Many of these models propose that rehearsal transfers information from

working memory into long-term memory (Atkinson & Shiffrin, 1968), and many models include some type of rehearsal “buffer” or “loop” (e.g., Waugh & Norman’s, 1965, recirculating loop; Salamé & Baddeley’s, 1982, articulatory rehearsal loop; Baddeley’s, 1992, phonological loop). Craik and Lockhart (1972) proposed a depth-of-processing explanation of why elaborative rehearsal is superior to maintenance rehearsal. Since then, many researchers have claimed that development of expertise in music, for example, requires not just repetitive practice, but also elaborative practice. This explanation would be consistent with our results if we assumed that more attention occurred under the more difficult reversed-lights condition than under the easier lights condition. However, any relationship between increased attention and “elaborative rehearsal” in rats and pigeons seems farfetched. We have no evidence that rats and pigeons engage in any type of rehearsal. Other animal researchers are not so skeptical. Helton (2005, 2007a, 2007b) argued that canines demonstrate “deliberate practice” in agility training. He argued that deliberate practice appears to be similar to elaborative rehearsal in Ericsson, Krampe, and Tesch-Romer’s (1993) theory of expertise development, which claims that deliberate practice, not genetics or talent, is the most important contributor to expertise acquisition. Perhaps future research will be able to discover the relation between a behavioral history producing stimulus control by practice cues and the types of practice or rehearsal (deliberate, elaborative, maintenance) presumed to be involved in human skill learning.

One approach to identifying similarities between skill acquisition in humans, rats, and pigeons is to explore the role of distributed practice in these procedures. For example, the present experiment provided probe trials with a particular density and distribution, without consideration of the values that should be optimal for skill learning. Distributed practice in human cognition is often claimed to be superior to massed practice (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013). The ideal distribution of guiding-cues trials and probe trials depends upon the interaction between these cues: How much do guiding-cues trials contribute to autonomy, and do probe trials contribute more directly? Reid, Folks, and Hardy (2013) recently measured cue interaction between alternating blocks of guiding-cues sessions and no-cue sessions in pigeons. We observed that for easy guiding-cues procedures, guiding-cues trials and no-cues trials appear to contribute equally to the development of autonomy. Yet, with a more difficult guiding-cues procedure (the simultaneous chain), guiding-cues trials appeared to increase autonomy more so than no-cues trials. Cue interaction is a relatively unexplored key factor in skill learning. The techniques described here may provide a methodology for comparing the roles of distributed practice in humans and lower animals.

How do the present results inform instructional procedures for children with learning disabilities to prevent or eliminate

prompt dependence? Prompt dependence is observed when stimulus control by the teacher's prompt fails to transfer to situational cues that should control that behavior. One possible implication of the present results is that prompt dependence could occur when the teacher's guiding cues are so effective ("leading the child by the hand") that little attention is allocated to the situational cues whose control would allow autonomous performance of the skill. The relation between skill learning and prompt dependence is not simple. For example, children may be quite proficient at producing the motor skill in the proper context, so control by context may be the major difficulty—not learning the motor skill per se. The procedures used in Fox, Reid, and Kyonka (2013), Reid et al. (2010), Reid, Folks, and Hardy (2013), and Reid, Rapport, and Le (2013) differ from that in the present experiment because they all trained a motor skill until it achieved accuracy and stability criteria before the transfer to a new stimulus condition. Some of these new conditions provided different guiding cues, and some provided no-cues conditions where the proper behavior pattern was controlled by a behavioral history of this pattern in a highly similar context (still inside the operant apparatus with the same levers and the food hopper and still hungry). The no-cues conditions would be most analogous to situations in which the instructor would like the child to produce the behavior pattern in a slightly different context, but without the instructor present. The new guiding-cues conditions would be most analogous to situations in which the instructor would like the behavior pattern to become controlled by available social or other environmental cues. Unfortunately, these distinctions are not well defined when the desired skill is "autonomous" versus when it is controlled by contextual cues.

Theoretical distinctions aside, published research with handicapped children can inform the direction in which research with rats and pigeons might be fruitful. Recognizing that severely handicapped children often become emotional in discrimination procedures involving nonreinforcement or extinction, Touchette (1971) implemented a novel modification of Terrace's (1963) "errorless" discrimination procedure normally involving stimulus fading. He measured the transfer of stimulus control in handicapped children by imposing an accuracy-dependent temporal delay at the beginning of each trial. During the delay, no guiding cues were provided, and he measured the child's go/no-go discrimination. Each correct response increased the duration of the delay, and each error decreased its duration. Touchette found that delaying the onset of the stimuli that initially controlled responding, rather than gradually fading them out, brought responding under tight control of the temporal cues. All children learned to respond before the external cue was provided. Touchette and Howard (1984) subsequently demonstrated that this procedure, called *delayed prompting*, is effective because anticipatory responding (prior to the cue) provides increased relative reinforcement rate and produces rapid transfer of stimulus control. Since then, other researchers have used

delayed-prompt procedures (Clark & Green, 2004) or provided the most potent reinforcers for unprompted responses (Karsten & Carr, 2009). These procedures are important because they help us understand and control the pernicious problem of prompt dependence in handicapped children. We summarize them here because these procedures can be implemented in the procedures we have described with rats and pigeons. In fact, a delayed-prompting study with rats is currently underway in this lab.

Returning to the implications of the present experiment, future research should explore whether prompt dependence can be reduced or eliminated by practice with less effective or more difficult guiding cues that require more focused attention.

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