

Changes in stimulus control during guided skill learning in rats

Alliston K. Reid*, Chelsea A. Nill, Brittney R. Getz

Wofford College, USA

ARTICLE INFO

Article history:

Received 15 August 2009
Received in revised form
31 December 2009
Accepted 4 January 2010

Keywords:

Behavioral organization
Sequence learning
Skill learning
Stimulus control
Rats

ABSTRACT

We examined the changes in stimulus control occurring during guided skill learning in rats. Twenty rats were trained to complete a left–right sequence of lever presses guided by the onset and offset of panel lights over their respective levers. Once sequence accuracy was high and stable, the rats were divided into two groups. For the No-Lights group, the lights were eliminated without changing the response requirements. Sequence accuracy decreased in all subjects, but accuracy was higher than that predicted by random chance. More practice produced greater autonomy and reduced dependence on the guiding lights. For the Reversed-Lights group, the lights were presented in reversed order without changing the response requirements. Sequence accuracy immediately plummeted and did not recover, violating expectations of automatization. The guiding lights appeared to overshadow other sources of stimulus control.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

When coaches and instructors teach complex skills to athletes and students, they usually provide both guiding cues and evaluative feedback. A dance instructor, for example, may demonstrate a sequence of dance steps, providing explicit guiding cues as the student simultaneously practices the steps. She may also correct errors and provide reinforcement for correct performance. The instructor eventually leaves, and the student must practice without guidance. Skilled performance previously controlled by the instructor's guiding cues must now, with practice, become autonomous. Such human skill learning has received much attention through extensive research and cognitive modeling (e.g., Anderson, 1982, 1996; Anderson et al., 2004; Fitts, 1964; Fu and Anderson, 2008; Schmidt, 1975; Wood and Neal, 2007).

Researchers working with rats and pigeons have also studied various forms of skill learning, but they have usually approached the subject by focusing on the effects of evaluative feedback, rather than guiding cues: "How does reinforcement create local organization in behavior?" (e.g., Mechner, 1992; Morse, 1966; Shimp, 1978; Shimp et al., 1990; Terrace, 2001). "How does reinforcement create behavioral units?" (e.g., Reid et al., 1991; Schwartz, 1981, 1982; Shimp, 1979). "How do functional response units develop?" (e.g., Reid et al., 2001; Schneider and Davison, 2005; Schneider and Morris, 1992). These questions emphasize the way in which reinforcement organizes combinations of discriminative stimuli and

responses into temporally integrated behavior patterns, which may be the non-human equivalent of skill learning. But as the example of the dance instructor indicates, this emphasis on the organizing properties of reinforcement may ignore the possibility that researchers may provide guiding cues to intentionally facilitate response selection and timing. The dance instructor may provide guiding cues, and then leave the student to practice without guidance until the behavioral pattern appears automatic. Important changes in stimulus control must occur during this process: the behaviors that were initially controlled by the instructor's cues must now become controlled by properties of the organism's own behavior.

Reid et al. (2001) provided a clear example of these temporally integrated behavior patterns created from combinations of discriminative stimuli and responses. They evaluated the contributions of two types of stimuli during the development of functional response units. In a probabilistic free-operant experiment with rats, food was delivered with probability 0.2 following two responses on the same lever (left–left or right–right) and with probability 0.6 following every pair of responses containing a changeover from one lever to the other (left–right or right–left). By manipulating the presence of demarcating stimuli, they compared the roles of (a) an exteroceptive demarcating stimulus (a tone pulse) and (b) differential reinforcement probability on the development of integrated two-response sequences. The tone demarcating the beginning and end of contingent response sequences facilitated the rapid development of local behavioral organization, yet the same behavioral organization developed slowly even in the absence of the tone. Thus, the behavior pattern was controlled by two very different stimuli: the tone, and the animal's sensitivity to differential reinforcement probability provided by the probabilistic schedule. The

* Corresponding author at: Dept. of Psychology, Wofford College, 429 N. Church St., Spartanburg, SC 29303, USA. Tel.: +1 864 597 4642; fax: +1 864 597 4649.

E-mail address: reidak@wofford.edu (A.K. Reid).

stimulus control by the tone is roughly analogous to a guiding cue provided by the dance instructor, and the control by the differential reinforcement probability (in the absence of the tone) is roughly analogous to the instructor allowing the student to practice alone.

The current study took a more direct approach by exploring the changes in stimulus control that occur during skill learning when explicit guiding cues are provided and then eliminated or reversed. We explored these changes with rats in a controlled environment that separated the roles of guiding cues from the effects of evaluative feedback (i.e., reinforcement). We trained rats to complete a left–right (L–R) sequence of lever presses guided by the onset and offset of panel lights over the respective levers. Once sequence accuracy was high and stable, we divided the rats into two groups. For the No-Lights group, the lights were eliminated without changing the response requirements. For the Reversed-Lights group, we presented the lights in reversed order, also without changing the response requirements. Comparison of the changes in sequence accuracy in the two conditions allowed us to examine changes in stimulus control.

To the extent that response–sequence learning in rats is equivalent to motor skill learning in humans, Fitts' (1964) stage model of human skill learning (as well as more recent models: Anderson, 1996; Anderson et al., 2004; Fu and Anderson, 2008; Wood and Neal, 2007) provides two related predictions for this experiment: more practice completing the response sequence in the presence of the guiding lights (i.e., more sessions of the Lights condition) should lead: (a) to progressively less dependence on the lights as discriminative stimuli (i.e., greater autonomy), and (b) to progressively more “automatization” of a L–R motor routine, such that the learned pattern of L–R lever presses should be less susceptible to disruption when the order of the lights is reversed.

2. Methods

2.1. Subjects

Twenty naïve 4-month-old female Long Evans rats were housed in individual cages in an animal facility that maintained constant temperature and humidity on a 12:12-light/dark cycle. Each subject was maintained at approximately 85% of its free-feeding body weight by providing supplemental food after each daily session. Water was freely available in the home cages. Two rats failed to reach our stability criteria and were dropped from the study.

2.2. Apparatus

The experiment utilized four standard Med Associates modular test chambers for rats measuring 30 cm × 24 cm × 22 cm. Each chamber was located inside an isolation chamber containing a ventilation fan, one 7-W 120-V nightlight, and a miniature closed-circuit TV camera on the ceiling. A sound generator produced a constant white noise at approximately 65 db. Each operant chamber contained two retractable levers on the front wall and two non-retractable 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 cm × 5 cm, was centered between the two 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 lever, 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/I) pellets. All four operant chambers were controlled by a single Compaq personal computer (Pentium 3) programmed in MED-PC IV, which controlled all experimental conditions and recorded every event and its time of occurrence with millisecond resolution.

2.3. Procedure

2.3.1. Training

Following initial lever-press training, subjects were exposed to a fixed ratio 1 (FR-1) schedule for pressing the front-right lever while a panel light was illuminated above that lever. Each session lasted until 45 food pellets were delivered or until 45 min had elapsed. Subsequently, each subject was exposed to one session of FR-1 for pressing the right-rear lever while the panel light was on above this lever. The purpose of this session was to ensure that all subjects were given the same amount of exposure to the reinforcement conditions on that right-rear lever before the experiment proper began, given that subjects required various amounts of original lever-press training.

In all subsequent conditions, the two front levers remained retracted and only the left and right levers on the rear wall were used. Trials were signaled by the presence of the houselight, whether the preceding trial ended in food delivery or timeout.

2.3.2. Lights condition

All subjects were exposed to the discrete-trials Lights condition. At the beginning of each trial, a light above the left lever was turned on. A press to this lever turned off this light and caused the right light to become illuminated. A press of this right lever turned off the right light, and a new trial then began. Completion of this left–right (L–R) response sequence resulted in pellet delivery. All other response sequences resulted in 10-s timeout during which the panel lights and houselight were off (the nightlight in the isolation chamber continued to provide general illumination), and lever presses had no programmed consequences. Sessions lasted either 45 min or until 150 trials were completed. This condition continued until sequence accuracy appeared to asymptote, remaining at 80% or greater accuracy for five sessions with no increasing or decreasing trend. Following completion of the Lights condition, half of the subjects were exposed to the No-Lights condition and half were exposed to the Reversed-Lights condition.

2.3.3. No-Lights condition

The response-reinforcer contingency in the No-Lights condition was identical to that of the Lights condition, but the panel lights over the levers were never illuminated. Incorrect response sequences continued to produce 10-s timeout with the houselight off. This condition was designed to measure performance accuracy when the guiding cues were removed, without altering the response requirements that produced reinforcement. Sessions lasted either 45 min or until 150 trials were completed. This condition lasted five sessions.

2.3.4. Reversed-Lights condition

The Reversed-Lights condition reversed the order of presentation of the panel lights over the two levers, but the response-reinforcer contingency was unchanged from the Lights condition. As before, left–right lever presses turned off and on the panel lights, but the lights followed a right–left pattern. This condition served two functions. First, one could interpret any change in performance during the No-Lights condition as being due to absence of exteroceptive guiding cues (as intended), but a drop in performance could also be produced by generalization decrement created by altered stimulus conditions (viz., the lights were eliminated). The Reversed-Lights condition provided illumination very similar to the Lights condition to minimize potential effects of generalization decrement; thus, little or no drop in responding would be expected. The second function of this condition was to assess the degree to which the learned pattern of L–R lever presses had become automatized, thus not susceptible to disruption by changes in the order of the lights. Sessions lasted either

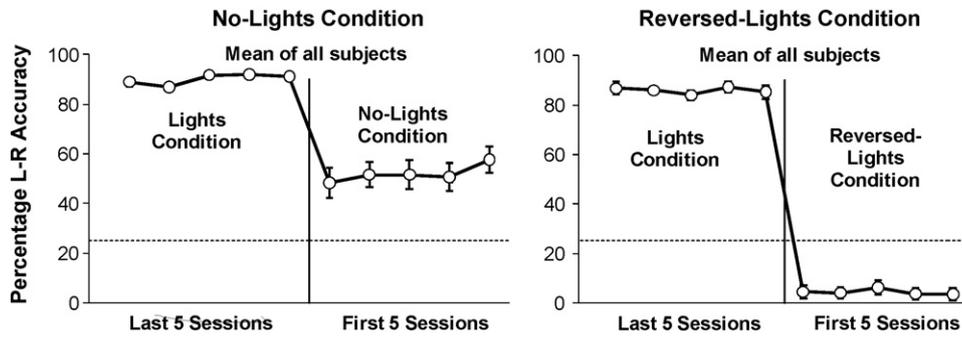


Fig. 1. This figure compares the mean percentage of L-R sequence accuracy in the final sessions of the Lights conditions to the initial sessions of the No-Lights condition (left panel) and the Reversed-Lights condition (right panel). The vertical line separates the conditions. The dashed horizontal line represents the accuracy predicted if levers were selected randomly. Error bars represent standard error of the mean.

45 min or until 150 trials were completed. This condition lasted five sessions.

3. Results

3.1. Lights condition

Eighteen subjects learned to produce the L-R sequence and met our stability criteria within 7–21 sessions with mean sequence accuracy reaching asymptote above 85% correct. Sequence accuracy was defined as the number of trials in which the L-R sequence produced a pellet delivery divided by the total number of trials per session, then converted to a percentage. The houselight signaled the beginning and end of each trial following pellet delivery or timeout. Fig. 1 depicts mean L-R sequence accuracy for the last five sessions in the Lights condition for the subjects subsequently shifted to the No-Lights condition (left panel) or shifted to the Reversed-Lights condition (right panel). The horizontal dashed line represents the expected sequence accuracy if lever-press selection were random.

3.2. No-Lights condition

Trials in the No-Lights condition were defined the same way as in the Lights condition, although the panel lights could no longer serve as supplemental beginning-of-trial cues. The houselight continued to signal the beginning and end of each trial following pellet delivery or timeout. The left panel of Fig. 1 displays the drop in L-R accuracy when the guiding lights were eliminated in the No-Lights condition. A 2 (condition) × 5 (session) repeated measures ANOVA showed a significant drop in L-R accuracy when the lights were eliminated, $F(1,4) = 26.273, p = 0.00686, \eta^2 = 0.868$. There was no effect of session and no interaction.

Even though accuracy dropped immediately when the lights were removed, accuracy during the first session of the No-Lights condition was greater than that predicted by random selection of levers, $\chi^2(10) = 407.9, p < 0.0001$. Thus, subjects had some ability to complete the response sequence even in the absence of guiding lights.

3.3. Reversed-Lights condition

When the other group of subjects was switched from the Lights condition to the Reversed-Lights condition, L-R sequence accuracy immediately plummeted (see the right panel of Fig. 1). A 2 (condition) × 5 (sessions) repeated measures ANOVA comparing the last five sessions of the Lights condition and the first five sessions of the Reversed-Lights condition demonstrated a significant drop in accuracy, $F(1,6) = 1291.07; p < 0.001, \eta^2 = 0.995$.

The drop in sequence accuracy may be compared to that observed in the No-Lights condition, as shown in Fig. 1. We hypothesized that if generalization decrement produced a drop in accuracy in the No-Lights condition, we would observe a smaller drop in the Reversed-Lights condition because it altered the stimulus environment less. Nevertheless, a mixed 2 (groups) × 2 (conditions) × 5 (sessions) ANOVA indicated that the drop in Reversed-Lights condition was significantly greater than the drop obtained in the No-Lights condition, $F(1,12) = 27.58, p < 0.001, \eta^2 = 0.697$.

Contrary to that observed in the No-Lights condition, L-R accuracy in the first session of the Reversed-Lights condition dropped well below that expected by random chance, $\chi^2(7) = 130.8, p < 0.0001$. Thus, L-R accuracy was well below that predicted by random chance when the guiding lights were reversed, and accuracy did not improve over the five sessions of this condition. Instead, lever pressing decreased as though responding were undergoing extinction, earning an average of 4.4 pellets per 45-min session, down from about 120 pellets per session in the Lights condition. Even though the response-reinforcement contingency had not been changed, subjects were unable to complete the same L-R sequence they had produced with such accuracy in the previous Lights condition.

Fig. 2 shows which particular response sequences were actually produced in the two conditions. As expected, the L-R sequence occurred most often in the Lights condition. However, in the Reversed-Lights condition, subjects produced the unreinforced right-left (R-L) sequence with increased frequency,

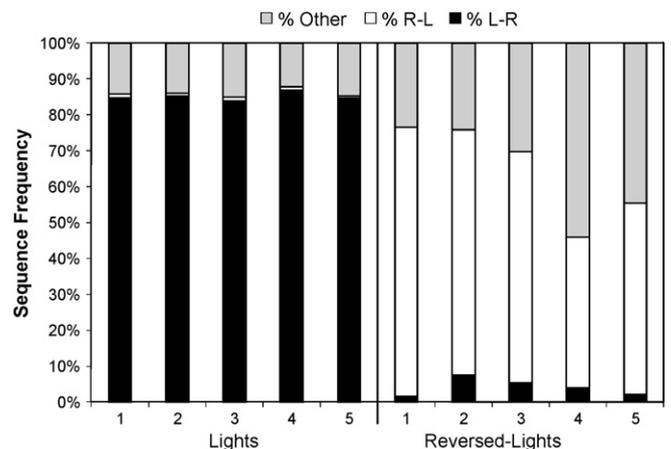


Fig. 2. This histogram depicts the frequency of three categories of response sequence observed in the final sessions of the Lights condition and the initial sessions of the Reversed-Lights condition. L-R sequences are depicted in black, R-L sequences in white, and L-L and R-R sequences were combined and depicted by diagonal stripes.

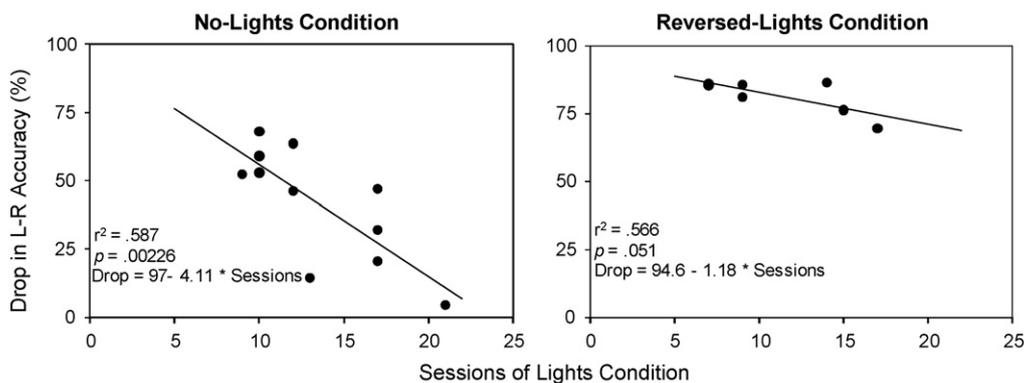


Fig. 3. This figure illustrates the relationship between the amount of exposure of each rat to the Lights condition and their subsequent drop in accuracy when switched to the No-Lights condition (left panel) and to the Reversed-Lights condition (right panel). Each point represents a different subject, and the regression lines represent the line of best fit for those points.

and L–R sequences fell below chance levels. The lights were presented in the “misleading” R–L order, and all subjects continued to “follow” the lights until lever pressing had nearly extinguished.

3.4. Effects of practice

Fig. 3 illustrates the relationship between the amount of exposure of each rat to the Lights condition (“practice”) and the subsequent drop in accuracy when switched to the No-Lights condition (left panel) and to the Reversed-Lights condition (right panel). The switch to the No-Lights condition produced drops in L–R accuracy across subjects that could be accurately described ($r^2 = 0.587$) by a regression line with a prominent negative slope (-4.11). Although correlational, this negative slope is consistent with the hypothesis that increased training in the Lights condition yielded less dependence on the lights—more practice of a skill (with guiding cues) led to greater autonomy (without the cues).

Although the slope was also slightly negative (-1.18) in the Reversed-Lights condition, more training in the Lights condition had less effect on accuracy. Even though the drop in sequence accuracy was dramatic (as was the decrease in overall amount of responding), the contribution of amount of training to the drop in sequence accuracy was small. Instead, errors were produced by “following the misleading” guiding lights, resulting in large percentages of R–L sequences (Fig. 2).

4. Discussion

The Lights condition demonstrated that animals learned a motor skill in the form of a left–right sequence of lever presses using lights as guiding cues. When these lights were removed in the No-Lights condition, sequence accuracy decreased yet remained higher than chance levels. This decrease reflects the animals’ reduced ability to complete the sequences based on stimulus control mediated by the animal’s own behavior.

As Fig. 3 depicts, more sessions of training in the Lights condition led to a smaller drop in accuracy when the lights were removed. As predicted, more practice in the presence of the guiding lights led to progressively less dependence on the lights as discriminative stimuli, and to greater control mediated by the animal’s own behavior (i.e., greater autonomy).

In contrast, when the order of the lights was reversed in the Reversed-Lights condition, sequence accuracy plummeted and responding approached extinction levels. Even though the response–reinforcer contingency never changed, response selection was controlled by the lights even when they no longer signaled

the correct levers. This stimulus control resulted in abnormally high levels of unreinforced R–L sequences. These R–L sequences were not frequent in the No-Lights condition, in which subjects were able to respond in the correct L–R order with about 50% accuracy (well above chance).

More practice in the presence of the guiding lights was associated with greater autonomy in the No-Lights condition. However, responding in the Reversed-Lights condition violated our predictions that more practice would also lead to progressively more automatization, and to less susceptibility to disruption by the reversed order of the lights. Whereas the slope in Fig. 3 (right panel) was still slightly negative (indicating some effect of practice), the major determinant of errors in the Reversed-Lights condition was “following the misleading” lights. We observed no evidence that the amount of training needed to fulfill our stability criteria produced an automatized motor program of L–R lever presses. Instead, we observed nearly complete disruption of the learned behavior pattern when the lights were reversed. Interestingly, no subjects were able to reacquire the correct L–R sequence within five sessions, and responding dropped nearly to extinction levels.

Why were the changes in accuracy levels so different in the No-Lights and Reversed-Lights conditions? Consider two interacting types of discrimination certainly involved in this procedure. Subjects needed to detect that the stimulus environment of the Lights condition had changed to that of the No-Lights or Reversed-Lights condition, and they needed to map these stimulus changes to potential changes in response–reinforcer contingency within each condition. The transition from the Lights condition to the No-Lights condition was designed to be easily detectable. However, the transition to the Reversed-lights condition was designed to be more difficult to detect: the panel lights continued to be presented one at a time (but with the order reversed), and each lever press continued to affect the lights.

In the No-Lights condition, the only stimuli available to guide response selection were provided by the subject’s own behavior. Because there was no change in response–reinforcer contingency, the required pattern of responding was consistent with the history of the subject’s own behavior as it completed the L–R sequence in the Lights condition. Thus, it is not surprising that accuracy was diminished but not eliminated.

However, although subjects in the Reversed-Lights condition also had a training history consistent with the contingency in effect, the condition pitted this training history against the inconsistent influence of the altered order of lights for control of response selection. Because sequence accuracy immediately plummeted in this interaction between competing sets of stimuli, we conclude there was stronger stimulus control by the “misleading” lights

and weaker control by the history of the subjects' own behavior. This interaction may be an overshadowing effect affecting operant behavior (Cheng et al., 2007; Pearce and Hall, 1978; Williams, 1975).

While the argument above explains why sequence accuracy dropped so dramatically in the first session of the Reversed-Lights condition, it does not adequately explain why accuracy did not improve over five sessions. Several studies have demonstrated high sensitivity to response sequence/reinforcer contingency in rats that lead to rapid adjustment of sequence production. Reid (1994) and Reid et al. (2008) trained rats to complete a 3-response sequence of lever presses, and in the middle of a session they changed the response contingency without warning. Subjects were able to detect the change within a few trials, and they began producing the new reinforced sequence usually before the end of the session. Bachá-Méndez and Reid (2006) and Bachá-Méndez et al. (2007) have also demonstrated similar rapid adjustments to unsignaled changes in sequence-reinforcer contingency in 2-response sequences (for discussion of discrimination of sequence-reinforcer contingency in concurrent schedules, see Schneider, 2008; Schneider and Davison, 2005). Because the required behavior pattern was not altered in the current study, it would have seemed simple for the subjects to learn to ignore the lights and continue responding as before, but that did not occur.

Referring to recent stage models of skill learning in cognitive psychology, Gluck et al. (2008) identifies a continuing problem, "... the three-stage model of skill learning is primarily descriptive. It won't help you predict how much practice you need to convert your skill memories to motor programs or give you pointers about how and when you should practice." (p. 144). The flexible methodology used in this experiment may be extended in future research to provide answers to these important questions. Simple alterations to the training and testing conditions should allow the controlled study of many factors that affect skill learning, such as massed versus distributed practice, frequency and duration of instruction, consistency in instruction style, attention and distraction, and the difficulty of the practiced skill.

Acknowledgements

We would like to thank Francis Mechner, Geoff White, and an anonymous reviewer for their helpful comments on an earlier version of this paper. We especially thank the students in Learning and Adaptive Behavior at Wofford College for running the subjects in this experiment, and for interesting discussions of the relation between response-sequence learning in rats and motor skill learning in humans. We are grateful to Wofford College for funding this research.

References

- Anderson, J.R., 1982. Acquisition of cognitive skill. *Psychol. Rev.* 89, 369–406.
- Anderson, J.R., 1996. ACT: a simple theory of complex cognition. *Am. Psychol.* 51, 355–365.
- Anderson, J.R., Bothell, D., Byrne, M.D., Douglass, S., Lebiere, C., Qin, Y., 2004. An integrated theory of the mind. *Psychol. Rev.* 111, 1036–1060.
- Bachá-Méndez, G., Reid, A.K., 2006. Acquisition of simple patterns of responses. *Mex. J. Behav. Anal.* 32, 155–177.
- Bachá-Méndez, G., Reid, A.K., Mendoza-Soylovna, A., 2007. Resurgence of integrated behavioral units. *J. Exp. Anal. Behav.* 87, 5–24.
- Cheng, K., Shettleworth, S.J., Huttenlocher, J., Reiser, J.J., 2007. Bayesian integration of spatial information. *Psychol. Bull.* 133, 625–637.
- Fitts, P., 1964. Perceptual-motor skill learning. In: Melton, A. (Ed.), *Categories of Human Learning*. Academic Press, New York, pp. 243–285.
- Fu, W.-T., Anderson, J.R., 2008. Dual learning processes in interactive skill acquisition. *J. Exp. Psychol. Appl.* 14, 179–191.
- Gluck, M.A., Mercado, E., Myers, C.E., 2008. *Learning and Memory: From Brain to Behavior*. Worth, New York.
- Mechner, F., 1992. *The Revealed Operant: A Way to Study the Characteristics of Individual Occurrences of Operant Responses*. Cambridge Center for Behavioral Studies Monograph Series, Cambridge, MA.
- Morse, W.H., 1966. Intermittent reinforcement. In: Honig, W.K. (Ed.), *Operant Behavior: Areas of Research and Application*. Appleton-Century-Crofts, New York, pp. 52–108.
- Pearce, J.M., Hall, G., 1978. Overshadowing the instrumental conditioning of a lever-press response by a more valid predictor of the reinforcer. *J. Exp. Psychol.: Anim. Behav. Process.* 44, 356–367.
- Reed, P., Schachtman, T.R., Hall, G., 1991. Effect of signaled reinforcement on the formation of behavioral units. *J. Exp. Psychol.: Anim. Behav. Process.* 17, 349–357.
- Reid, A.K., 1994. Learning new response sequences. *Behav. Process.*, 147–162.
- Reid, A.K., Chadwick, C.Z., Dunham, M., Miller, A., 2001. The development of functional response units: the role of demarcating stimuli. *J. Exp. Anal. Behav.* 76, 303–320.
- Reid, A.K., Dixon, R., Gray, S., 2008. Variation and selection in response structures. In: Innis, N. (Ed.), *Reflections on Adaptive Behavior: Essays in Honor of J.E.R. Staddon*. MIT Press, Cambridge, MA, pp. 51–86.
- Schmidt, R.A., 1975. A schema theory of discrete motor skill learning. *Psychol. Rev.* 82, 225–260.
- Schneider, S.M., 2008. A two-stage model for concurrent sequences. *Behav. Process.* 78, 429–441.
- Schneider, S.M., Davison, M., 2005. Demarcated response sequences and the generalised matching law. *Behav. Process.* 70, 51–61.
- Schneider, S.M., Morris, E.K., 1992. Sequences of spaced responses: behavioral units and the role of contiguity. *J. Exp. Anal. Behav.* 58, 537–555.
- Schwartz, B., 1981. Reinforcement creates behavioral units. *Behav. Anal. Lett.* 1, 33–41.
- Schwartz, B., 1982. Interval and ratio reinforcement of a complex, sequential operant in pigeons. *J. Exp. Anal. Behav.* 37, 349–357.
- Shimp, C.P., 1978. Memory, temporal discrimination, and learned structure in behavior. In: Bower, G.H. (Ed.), *The Psychology of Learning and Motivation*, vol. 12. Academic Press, New York, pp. 39–76.
- Shimp, C.P., 1979. The local organization of behavior: method and theory. In: Zeiler, M.D., Harzem, P. (Eds.), *Advances in Analysis of Behavior* (Vol. 1). Reinforcement and the Organization of Behavior. Wiley, Chichester, England, pp. 261–298.
- Shimp, C.P., Childers, L.J., Hightower, F.A., 1990. Local patterns in human operant behavior and a behavior model to interrelate animal and human performances. *J. Exp. Psychol.: Anim. Behav. Process.* 16, 200–212.
- Terrace, H., 2001. Chunking and serially organized behavior in pigeons, monkeys and humans. In: Cook, R.G. (Ed.), *Avian Visual Cognition. Comparative Cognition Press, Medford, MA* [On-line] available at: www.pigeon.psy.tufts.edu/avc/.
- Williams, B.A., 1975. The blocking of reinforcement control. *J. Exp. Anal. Behav.* 24, 215–225.
- Wood, W., Neal, D.T., 2007. A new look at habits and the habit–goal interface. *Psychol. Rev.* 114, 843–863.