JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2010, **94,** 315–326 NUMBER 3 (NOVEMBER)

CHOICE IN QUAIL NEONATES: THE ORIGINS OF GENERALIZED MATCHING

Susan M. Schneider

UNIVERSITY OF THE PACIFIC

AND

Robert Lickliter

FLORIDA INTERNATIONAL UNIVERSITY

Although newborns have surprised scientists with their learning skills, proficiency on concurrent schedules of reinforcement requires (in effect) the ability to integrate and compare behavior–consequence relations over time. Can very young animals obey the quantitative relation that applies to such repeated choices, the generalized matching law? The provenance of the skill is not well understood, and this study provides the first investigation of matching in neonates. Northern bobwhite (*Colinus virginianus*) hatchlings pecked left and right targets on a touchscreen for heat delivery on a concurrent variable-interval reinforcement schedule. Within 5 days after hatching, the chicks showed sensitivity levels significantly greater than zero, but short of typical adult levels. However, stable sequential patterns emerged almost immediately, including a consistent choose-rich tendency after unreinforced responses, one that entails some degree of temporal integration. These exploratory data suggest that the basic ability to match develops quickly in this precocial species, but that more extensive experience may be required to achieve the higher sensitivities typically seen in adults.

Key words: choice, generalized matching law, neonates, sequential analysis, heat reinforcement, touchscreen peck, northern bobwhite

The generalized matching law is a widely applicable quantitative relation that applies to repeated choices between different schedules of reinforcement (e.g., Davison & McCarthy, 1988; Mazur, 2001; Sugrue, Corrado, & Newsome, 2004). The usefulness of the equation is sufficiently well established that neuroscientists have even begun using matching to understand the neurophysiological basis of choice (e.g., Loewenstein & Seung, 2006; Platt & Glimcher, 1999; Sugrue et al., 2004). The provenance of this skill is not well understood, however, and this study provides the first investigation of matching in neonates.

In the generalized matching law,

$$\frac{B_1}{B_2} = b\left(\frac{R_1}{R_2}\right)^a, \qquad (1)$$

B refers to behaviors emitted and *R* to reinforcers obtained on two alternatives. The parameter *b*, inherent bias, measures a constant preference for one response over the other, such as an easier over a more effortful behavior. The parameter *a*, sensitivity to reinforcement, measures the change in response ratios as a function of changes in reinforcer ratios, with a value of 1 representing ‘‘strict’’ matching. Across a range of variables, adult organisms often exhibit ‘‘undermatching’’ (sensitivities of less than 1, typically 0.8–0.9, e.g., Anderson, Velkey, & Woolverton, 2002; Schneider & Davison, 2005; Wearden & Burgess, 1982; Williams, 1988), indicating a tendency to stabilize closer to indifference. In its logarithmic form, the equation becomes an easily fitted straight line:

$$\log\frac{B_1}{B_2} = a\log\frac{R_1}{R_2} + \log b. \qquad (2)$$

Neonates of several species have been shown to be capable of operant learning immediately after birth (e.g., dogs—Bacon & Wong, 1972; chickens—Delsaut, 1991; rats—Flory, Langley, Pfister, & Alberts, 1997); indeed, newborn quail are able to generalize (e.g., Schneider & Lickliter, 2009, 2010). Because matching

---

This work was supported by National Institutes of Health Grant R01-HD048423 (to R. L.). We thank Chris Krägeloh for his helpful comments on a previous version of the manuscript. We also thank Michael Davison for valuable service as a sounding board at various points in the process.

Correspondence may be addressed to the first author at Department of Psychology, University of the Pacific, Stockton, CA 95211 (e-mail: sschneider@pacific.edu).

doi: 10.1901/jeab.2010.94-315

entails the ability to make choices that track multiple behavior–consequence relations, however, it may be a higher-order skill that requires more extensive experience.

Accordingly, we investigated matching in a precocial galliform species, the northern bobwhite, immediately after hatching. Matching might not occur at all; if it did, it might not look like adult matching, instead showing developmental effects. Such data inform matching theory (e.g., Gallistel et al., 2007; Rachlin, Green, & Tormey, 1988) and, more generally, operant involvement in developmental psychobiology (e.g., Schneider, 2003, 2007).

Because we wanted to study just the neonatal phase in this rapidly developing species, we trained the birds during their first 5 days after hatching. Only one pair of schedules could thus be investigated in each individual, and a group design was employed. We developed a touchscreen preparation with left and right targets at which the chicks pecked for brief presentations of heat (see Schneider & Lickliter, 2009, 2010). The targets were demarcated by ''X'' and ''O'' symbols, enhancing discriminability and allowing us to investigate perceptual preference as well as the development of choice. Finally, many studies have revealed moment-to-moment order during choice on concurrent schedules (e.g., Schneider & Davison, 2006). To enable exploration of any underlying dynamics of choice in neonates, a sequential analysis was performed.

METHOD

Subjects

Northern bobwhite (*Colinus virginianus*) chicks were hatched weekly in our lab and reared socially in a sound-attenuated rearing room. Food and water were freely available. To minimize the stress of individual isolation in the operant chamber for this highly social species, a fuzzy surrogate of appropriate size and color pattern was placed in the rearing bin after hatching. A similar surrogate remained centered in the back of the operant chamber during testing. A combination of random assignment and matching based on weight was utilized (see Schneider & Lickliter, 2010). Each of the four scheduled reinforcement ratio groups reached similar average final weights (range 8.8 g to 9.3 g); however, in the present study, weight was uncorrelated with performance. The 54 chicks that completed the study were evenly distributed across the four ratios, in a between-groups design.

Apparatus

We attached an infrared-based touchscreen detection frame (Elo CarrollTouch Extended Resolution) to a 380-mm flat-screen monitor. The touchscreen was programmed in Visual Basic to record pecks in two target areas. Because the monitor produced a small amount of heat that could attract the chicks, two layers of 2.2-mm acrylic sheeting were inserted between the touchscreen frame and the bottom half of the monitor, and the chicks pecked the acrylic. The photobeam array was set at 8 mm from the acrylic cover, a distance that allowed the chicks' beaks to register a touch.

A box of 330 mm × 180 mm × 180 mm was the operant chamber. An open side fitted snugly lengthwise along the frame of the touchscreen, enabling a chick to approach the entire lower monitor area. An acrylic sheet over the floor was covered by the same plastic liner used in the rearing bins, at the level of the bottom edge of the touchscreen detection area. A 250-W white heat lamp (127 mm in diameter) was suspended above the chick's position as it pecked at the targets, at the level of the top of the chamber.

The apparatus was enclosed within a sound-attenuating cubicle (Med Associates) of 559 mm × 559 mm × 356 mm inside dimensions. This cubicle and the controlling computer were housed inside a completely partitioned enclosure.

Procedure

Autoshaping. The two onscreen pecking targets were white rectangles 48 mm high and 56 mm wide against a dark red background. An ''X'' and ''O'' were counterbalanced on these targets; each was 13 mm tall and 11 mm wide, centered on the target. The targets in turn were centered at the bottom of the screen, with 7 mm between them.

An autoshaping procedure was used to establish target-pecking. The two targets simultaneously appeared and disappeared in a 10-s on/10-s off pattern. At the end of the target-on period, 0.3 s of heat was delivered from the heat lamp. A peck to either target immediately caused the disappearance of both and operated the heat lamp, which was accompanied by a relay click. After the first four pecks, the autoshaping sequence ended, the targets remained on, and a continuous reinforcement schedule took effect for six pecks. Targets operated individually from that point, and, to enhance the likelihood of response acquisition and maintenance, all target pecks produced visual feedback: The target blinked off for 0.2 s.

A concurrent variable-interval variable-interval (conc VI VI) schedule then began, with a programmed interreinforcer interval averaging 2 s. Four ratios of independently scheduled reinforcement were utilized: 1:4, 1:9, 4:1, and 9:1, using the progression of Fleshler and Hoffman (1962; five intervals sampled with replacement). The schedule for the 4:1 ratio was accordingly conc VI 2.5-s VI 10-s. No changeover delay was included. The autoshaping session was run the morning of the day the chicks turned 24 hr old, and was 15 min in duration.

All chicks that pecked at least 35 times during the autoshaping session were retained in the study. 80% of the birds met this response criterion (the same success rate as in Schneider & Lickliter, 2009, 2010), and these chicks, 80 in number, continued on to participate in the training sessions. Most of these chicks pecked between 40 and 100 times.

The chicks weigh only 6–7 g upon hatching, and their thermoregulation ability and weight increase steadily during early development (Borchelt & Ringer, 1973). Throughout the study, starting chamber temperatures were set based on age and weight in order to achieve relatively constant motivation across and within chicks, while minimizing stress (see Schneider & Lickliter, 2010). Toward this end, relatively warm temperatures were used (18–23°C), just sufficient for adequate responding. Experimental attrition was relatively high as a result (as is typical in neonate research). However, response rates maintained well, declining only slightly on average over the course of the study (for the chicks that met the stability criteria; 5.7 responses/min for the first three training sessions, 5.0 responses/min for the last three sessions).

Training. During training (the second through the tenth sessions), chicks that weighed over 7.5 g were given 20-min sessions; lower-weight chicks continued at 15 min. Sessions were run twice daily, once in the morning and again in the afternoon.

The same four independently scheduled ratios were continued, but with a 3-s nominal interreinforcer interval. The schedule for the 4:1 ratio was thus conc VI 3.75-s VI 15-s; for the 9:1 ratio, VI 3.33-s VI 30-s. Ten Fleshler-Hoffman intervals were ordered randomly without replacement. Heat duration per reinforcer delivery was increased to 0.4 s, and a 0.5-s changeover delay (COD) was used. (That is, after a response on one side, no reinforcer was available on the other until at least 0.5 s had passed; this technique helps prevent inadvertent reinforcement of a sequence of responses. The duration was chosen based on pilot testing.) To control for possible differences across hatches, at least two different scheduled reinforcement ratios were run each week. Stable data from at least 6 chicks were obtained for each of eight groups: the four scheduled ratios in combination with the counterbalanced X and O on the targets. Finally, to enable the sequential analyses, the time of all events was recorded for all of the 1:9 and 9:1 sessions.

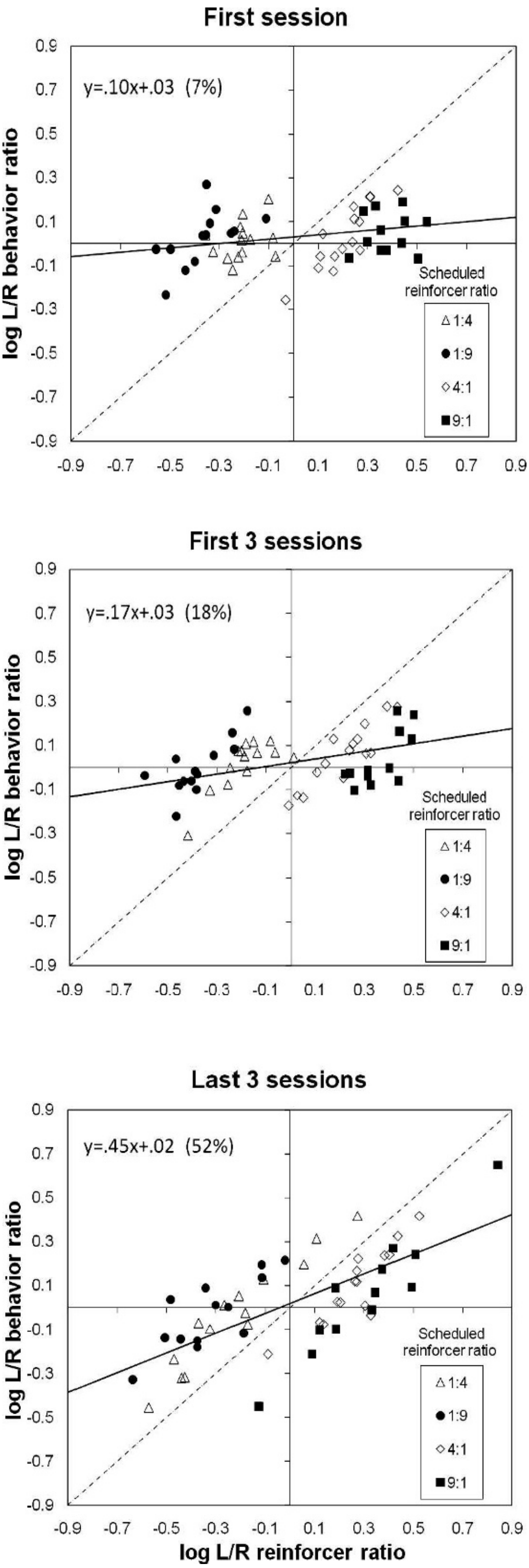
To ensure sufficient contact with the concurrent schedules, data were used only from chicks that pecked at least 400 times and received at least 250 reinforcement deliveries during the nine training sessions. Seventy-one percent (57) of the autoshaped chicks met these requirements. Because of the independent scheduling, the obtained reinforcer ratio varied, and a stability criterion covered this moving target as follows: The behavior ratio for the lean/rich sides was divided by the corresponding reinforcer ratio. The standard deviation of this ratio over the last three sessions then had to be less than 0.18. Ninety-five percent of the chicks met this criterion, and all of these subjects met a further requirement that the responses-to-reinforcers ratio be at least 1.4 (to allow for sufficient variation in sensitivity and bias).

The final database was thus composed of 54 chicks (12 chicks at the 9:1 reinforcer ratio, 13 chicks at 1:9, 14 chicks at 1:4, and 15 chicks at 4:1). Data were aggregated over the first three and the last three training sessions.

RESULTS

Matching

Figure 1 shows the obtained logarithmic response and reinforcer ratios in a developmental series for the full 54-point data set,



First session

←

Fig. 1. Developmental matching series for the full data set. The log L/R (left/right) behavior ratios are plotted as a function of the obtained log L/R reinforcer ratios, grouped by scheduled reinforcer ratio. The equation for the best-fit linear regression is provided, with percent variance accounted for in parentheses. The dashed line indicates strict matching. Axis labels are displaced for readability.

grouped according to scheduled reinforcer ratio, and combined across the counterbalanced discriminative stimuli (X and O). A least-squares linear regression was performed to fit the generalized matching equation; the sensitivity parameter value corresponds to the slope, and the log bias value to the y-intercept. Strict matching (sensitivity and bias of 1) is indicated in all figures by the dotted line through the origin. Despite unusually rich schedules, few chicks approached strict matching.

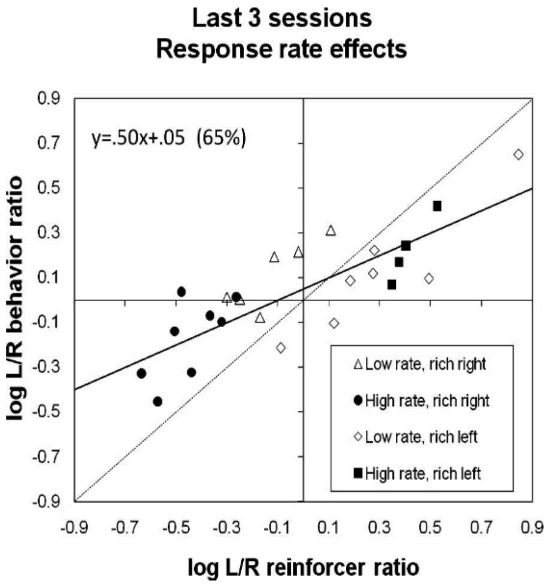
A steady increase in sensitivity occurred over the course of training, with a final value in the 0.4–0.5 range. The slopes were significantly different in the first three and last three sessions, $t(104) = 3.57$, $p < .01$, and the behavior ratios for most chicks moved in the direction of matching, Wilcoxon signed-ranks test, $T(49) = 298$, $p < .001$.[1] A small bias toward the left remained constant.

Figure 2 contrasts the results for chicks with high (>1000) and low (<550) response totals over the nine training sessions. These chicks were approximately evenly distributed across reinforcement ratio categories. For both the rich right and rich left groups, high responders stabilized at more extreme reinforcer ratios, with 11 of 12 reaching absolute log ratios of greater than 0.3. Low-responding chicks remained closer to indifference, with only 4 of 13 reaching that level. More extreme reinforcer ratios were more efficient because the scheduled reinforcer distributions were more extreme (absolute log values of 0.60 and 0.95 for the 1:4/4:1 and 1:9/9:1 ratios).

To check whether high responders simply started with more extreme distributions and

---

[1] The five points that fell in the ''wrong'' quadrants in the bottom graph inflated the slope only slightly: Without them, the slope was 0.44 rather than 0.45, and the variance accounted for, 53% rather than 52%. The Wilcoxon test was performed without these outliers; with them included, the results remained significant, but at the $p < .05$ level, $T(54) = 511$, $z = 1.99$.

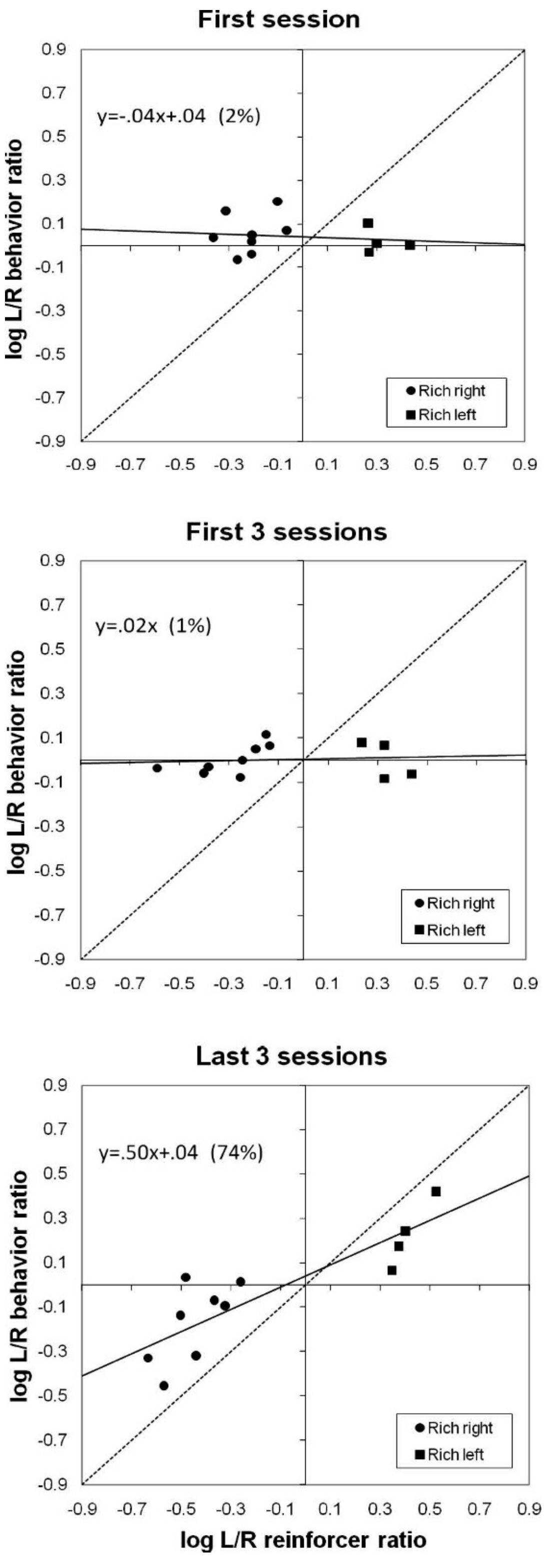


Last 3 sessions
Response rate effects

Fig. 2. Matching results for the last three sessions for high-responding (>1000 responses) and low-responding (<550 responses) chicks. The log L/R behavior ratios are plotted as a function of the obtained log L/R reinforcer ratios, grouped by scheduled reinforcer ratio. The equation for the best-fit linear regression is provided, with percent variance accounted for in parentheses. The dashed line indicates strict matching. Axis labels are displaced for readability.

remained there, Figure 3 presents their developmental series of matching graphs. As for the full data set, slope increased over time, ending in the 0.4–0.5 range. The slopes for the first three and last three sessions were significantly different, $t(20) = 4.23$, $p < .001$, and a Wilcoxon signed-ranks test confirmed that the behavior ratios for most chicks moved in the direction of matching, $T(12) = 4$, $p < .01$. A small bias toward the left side persisted.

Figure 4 shows the results for the X-O counterbalancing. For the rich left group, the overlapping symbols suggested that no behavior ratio bias existed (confirmed by statistical test, Mann-Whitney $U(12, 15) = 67$, $p > .05$). For the rich right group, however, a



First session

First 3 sessions

Last 3 sessions

→

Fig. 3. Developmental matching series for high-responding chicks (>1000 responses). The log L/R behavior ratios are plotted as a function of the obtained log L/R reinforcer ratios. The equation for the best-fit linear regression is provided, with percent variance accounted for in parentheses. The dashed line indicates strict matching. Axis labels are displaced for readability.

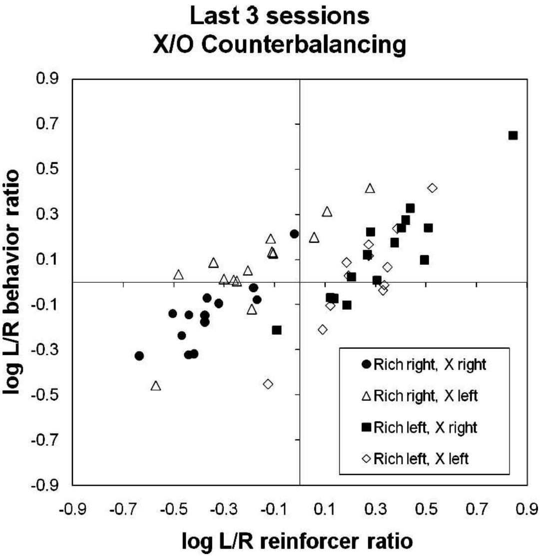


Fig. 4. X/O counterbalancing results for the full data set over the last three sessions. The log L/R behavior ratios are plotted as a function of the obtained log L/R reinforcer ratios. Axis labels are displaced for readability.

bias toward X occurred, $U(13, 14) = 28$, $p < .01$. The rich right, X right data were in the range expected from the corresponding rich left results, but the rich right, X left data tended to be positive rather than negative, as expected. However, further analysis showed that this result might be explained at least in part by differences in the obtained response and reinforcer rates in the rich right groups: 92% of the rich right, X right group produced more than 350 reinforcers, for example, whereas only 50% of the rich right, X left group fell in that high-reinforcement category. Both rich left groups produced similar intermediate values (60% for X right, 67% for X left). From Figures 1–3, greater exposure appears to produce greater sensitivity, as would be expected. Perhaps greater exposure and/or greater sensitivity might override any initial bias toward X.

Sequential Analysis

A sequential analysis was performed for the 1:9 and 9:1 data following the method of Bakeman and Gottman (1986; see Schneider & Davison, 2006, for a more detailed explanation). Based on the observed number of occurrences of each response, chance levels of each of the four Lag 1 patterns (left–left, left–right, right–left, and right–right) were determined. The actual number of occurrences of these patterns was compared to these expected values, and z-scores calculated on that basis. A positive z-score indicates more instances of that pattern than expected by chance. For both sequential analysis figures, the statistically significant Bonferroni-corrected z-scores at the .05 level were 2.6 (one-tailed) or 2.8 (two-tailed). Both of the patterns that emerged have occurred previously under related conditions (e.g., Schneider & Davison, 2006).

Figure 5 compares the sequential analysis results for unreinforced leading responses over the first three and last three sessions. The chicks preferentially followed unreinforced responses on either side with a response on the rich side, with only 4 of 100 points being inconsistent for the first three sessions, $\chi^2(1) = 85$, $p < .001$, and 5 of 100 for the last three sessions, $\chi^2(1) = 81$, $p < .001$. The rich right chicks tended to show larger differences from chance than the rich left chicks (average absolute *z*-score of 3.3 compared to 2.3). Again, reinforcer and response rates correlated with this result: Rich right chicks received more total training reinforcers on average (426 vs. 364 for rich left) and produced more responses (787 vs. 656).

Figure 6 presents the sequential analysis results for reinforced leading responses over the first three and last three sessions. Here another laterality effect occurred. For the rich left group, whichever response was reinforced tended to be immediately repeated. For example, a reinforced right choice was more likely than chance to be followed by another right (albeit seldom exceeding individual statistical significance levels for the *z*-scores). For the rich left group over the first three sessions, only 8 of 48 failed to follow this repetition pattern, $\chi^2(1) = 21$, $p < .001$; for the last three sessions, only 5 of 48 failed, $\chi^2(1) = 30$, $p < .001$. The most notable change over time was the disappearance of the only major conflict with the repetition pattern (Chick 1:9−5).

In contrast, for the rich right group, no pattern was evident for the first three sessions, and the repetition pattern suggested in the last three sessions was not as strong or consistent. However, the average tendency over time was a

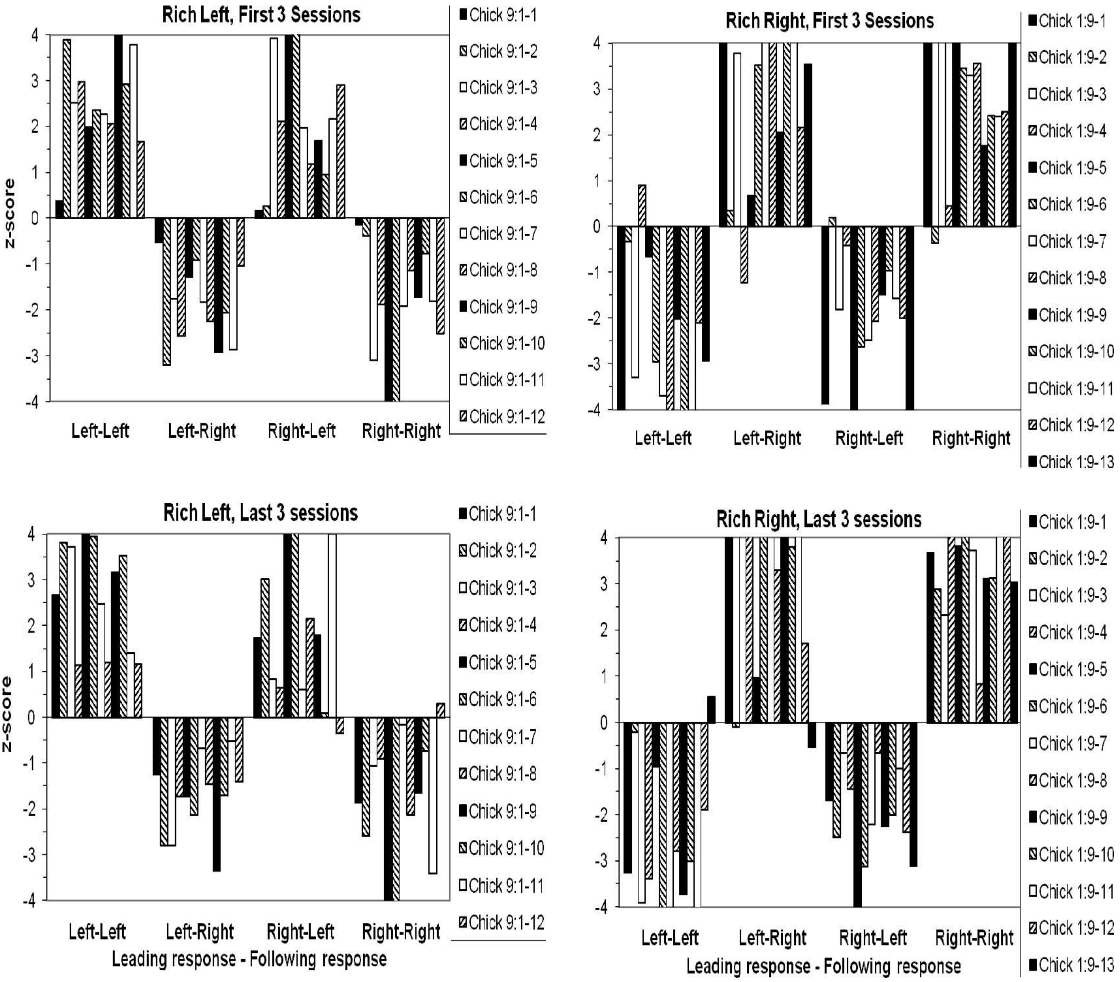


Fig. 5. Developmental series of sequential probability results for unreinforced leading responses, for the 9:1 (rich left) and 1:9 (rich right) groups. The *z*-scores are based on the difference between the expected and observed frequencies of each of the four Lag 1 response patterns (e.g., left-left; see text for explanation). Positive *z* scores indicate more occurrences of that pattern than expected from chance.

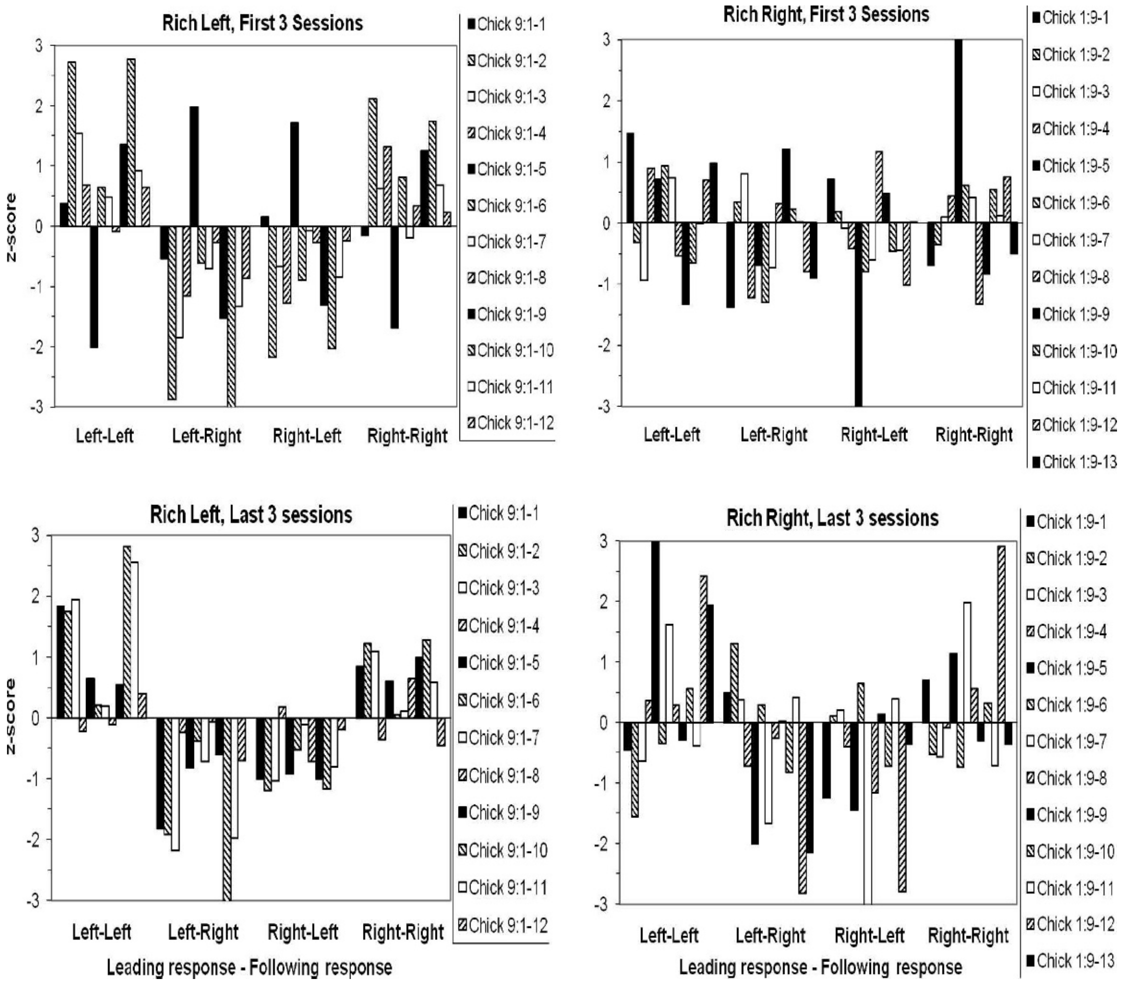
move toward the repetition pattern: Considering data points positive if they followed the pattern and negative if they did not, the average rich right *z*-score almost doubled, changing from 0.29 to 0.56. In addition, another possible effect of response and reinforcement rate was noted. The 5 rich right chicks with the strongest repetition patterns in the last three sessions had higher average response and reinforcement totals than the 5 that departed most from that pattern (533 vs. 390 reinforcers; 1041 vs. 698 responses).

Finally, as a sample, data allowing sequential analyses had been obtained from six 1:4 chicks. These results were similar in all respects to the 1:9 results, except that the postreinforcement repetition pattern was as strong as it was for the 9:1 chicks.

DISCUSSION

Northern bobwhite neonates choosing between two concurrent schedules of heat reinforcement showed increasing sensitivity over time, and their data could be described by the generalized matching law. This is the first demonstration of matching in neonates.

By the end of the study, when the chicks were just 5 days old, their response rates matched reinforcer rates with sensitivities up


Rich Left, First 3 Sessions

Rich Right, First 3 Sessions

Rich Left, Last 3 sessions

Rich Right, Last 3 sessions

Fig. 6. Developmental series of sequential probability results for reinforced leading responses, for the 9:1 (rich left) and 1:9 (rich right) groups. The *z*-scores are based on the difference between the expected and observed frequencies of each of the four Lag 1 response patterns (e.g., left-left; see text for explanation). Positive *z* scores indicate more occurrences of that pattern than expected from chance.

to 0.4 to 0.5. Higher response and reinforcer rates, and thus more exposure to the concurrent schedules, were associated with higher sensitivity and stronger sequential patterns. As in adults, sensitivity did not appear to depend on the scheduled reinforcer ratios.

The developmental series of matching graphs, the sequential analyses revealing the early emergence of a choose-rich strategy after nonreinforcement, and the data on the changing behavior and reinforcer ratios confirm that, as a group, the chicks were sensitive to these complex reinforcement contingencies. Response rates remained relatively constant over time; were the chicks entirely insensitive, their response distributions would have been expected to remain relatively constant also.

Their sensitivity was limited, however. While most chicks modified their responding in the direction of matching, a minority actually moved in the opposite direction. Further, assuming little bias, only a few chicks approached the typical stable adult sensitivities of 0.8–0.9. Finally, in scatter plots, relatively few points can determine the slope of the best-fit linear regression. The final sensitivity values of 0.4–0.5 accurately characterize only the performance of the chicks that were most sensitive.

Stability

For experienced adults on rapidly changing concurrent schedules, the time to matching stability after a change can be very fast indeed (e.g., within five reinforcer deliveries, Davison, Krägeloh, Fraser, & Breier, 2007; also see Bailey & Mazur, 1990; Davison & Baum, 2000). For naive adults, some evidence suggests that sufficient exposure can also be relatively short. Gallistel et al. (2007) found matching in naive adult mice within the first few sessions on independent concurrent interval schedules, with little change in response proportions thereafter. However, the response type in this study was not discrete. In a standard lever-pressing preparation, Shull and Pliskoff's (1967) 2 naive adult rats reached stability within 300–350 reinforcement deliveries. Given the ubiquity of operant choice, adults may have had relevant experience in the nonresearch context that could have influenced their performance.

The present study investigated the initial emergence of matching in neonates with minimal experience of any sort. For comparison to Shull and Pliskoff's (1967) results, the average number of reinforcers the chicks received in the nine training sessions was 472. For the high-responding, high-reinforcement-rate chicks of Figure 3, the average was 749. Did this exposure level allow these chicks to approach stability by the end of this short study? It is difficult to speculate. Given the differences in procedure, no direct comparisons to the adult literature are possible. Indeed, under some circumstances, adults on concurrent schedules can produce stable sensitivity values in the same range (0.4–0.5, see Anderson et al., 2002). We can conservatively conclude only that the northern bobwhite chicks did demonstrate matching to some degree.

Methodology

Due to the necessity of adapting the standard choice preparation to the requirements of neonates, several novel characteristics of our preparation deserve consideration. While heat reinforcement has been demonstrated in a number of vertebrate species (e.g., Satinoff & Hendersen, 1977; Weiss & Laties, 1961), this is only the second such study of matching (the first, Silberberg, Thomas, & Berendzen, 1991, used humans). However, the wide range of demonstrably effective consequences in the generalized matching law (e.g., Anderson & Woolverton, 2000; Belke & Belliveau, 2001; Cliffe & Parry, 1980; Hollard & Davison, 1971; Hutton, Gardner, & Lewis, 1978) suggests that the reinforcement modality was unlikely to have been a major factor.

This appears to be one of the first matching studies utilizing rich schedules, which in this preparation were necessary to maintain responding. Further, the obtained reinforcer ratios necessarily tracked the obtained response ratios to a degree, because the independent scheduling made this a partially closed system (Schofield & Davison, 1997). Given the chicks' size, even the touch of a touchscreen may have been relatively effortful. Perhaps the low response rates represent a relatively efficient way to maximize heat reinforcement while minimizing effort.

Whatever the causes, the combination of rich schedules, low response rates, and independent scheduling meant an unusual feedback function, one dependent on individual response distribution and timing. The average responses/reinforcers ratio was only 1.75, meaning that, for an average chick with a training total of 825 responses, 354 would have been unreinforced. The range of possible sensitivity and bias values obviously remained large. More extreme obtained reinforcer ratios than scheduled could potentially have occurred had the chicks perseverated on the rich side. A degree of overmatching would have been possible, and strict matching was quite achievable. (Assuming that they showed no bias, a few chicks did indeed approach strict matching.)

Choice studies utilizing primarily rich schedules appear to be few in number. However, as part of a study focused on attention deficit disorder, Kollins, Lane, and Shapiro (1997) investigated matching in 6 normal children 8 to 11 years old, utilizing an independently scheduled series of concurrent schedules. Starting with conc VI 3-s VI 3-s, four succeeding schedules became steadily leaner, from conc VI 3-s VI 6-s, to conc VI 3-s VI 9-s, ending with conc VI 3-s 24-s (with the rich side alternating). Participants had an hour of experience on each schedule in one block of time, less exposure per schedule than in the current study. For the 3 girls among the participants, the reinforcer of playing a video game appeared to be ineffective, and two of the resulting slopes were negative. For the 3 boys, sensitivities were in a more normal range: 0.45, 0.61, and 0.84. The fact that sensitivity could be as high as 0.84 on these rich schedules may be significant.

Kollins et al. (1997) used a 2-s changeover delay. Short changeover delays like ours (0.5 s) sometimes result in decreased sensitivity because of insufficient discriminability between successive responses on different sides (e.g., Davison & McCarthy, 1988). Our use of discriminative stimuli on the targets was intended to help prevent this effect. Further, because response rates were usually less than 10 responses/min, the changeover interresponse time (IRT) was seldom very short. For the 1:9 and 9:1 ratios, the median of the average changeover IRTs was 10 s for unreinforced responses. Averaged across chicks, only 3% of these IRTs were shorter than 1 s, and only 14% were shorter than 2 s. (Postreinforcement pausing occurred, as indicated by consistently longer postreinforcement than unreinforced changeover IRTs. Presumably the presentation of heat produced a period of satiation.) Finally, a follow-up group of 6 chicks with a 1.5-s COD showed sensitivity results indistinguishable from those for the 0.5-s COD. Thus, the low sensitivity values appear unlikely to have been a result of the short COD.

Stimulus Complexity and Laterality

The literature on perception suggests that ''X'' tends to be a stronger reinforcer than the less complex ''O,'' even in infants (e.g., Barnes & Baron, 1961; cf. Caron & Caron, 1968; McCall & Kagan, 1967). This expectation was confirmed for the rich right group, but the effect was minor, and confounded by obtained reinforcement rate.

Casey and Lickliter (1998) found a tendency to turn to the left in newly hatched bobwhite chicks. A consistent left bias was present in our matching data; however, the maximum log value for bias was only 0.05.

Molecular Implications and the Question of Provenance

After unreinforced responses, chicks produced a choose-rich pattern that emerged during the first three sessions and remained stable. Discrimination of the rich side requires the ability to detect and (in effect) compare different probabilities of reinforcement over time. In contrast, reinforced responses were likely to be immediately repeated, a simple temporal contiguity-based strengthening effect of reinforcement.

The postreinforcement pattern was considerably weaker than the choose-rich pattern. Oddly, the 1:9 group that received more responding and reinforcement experience showed a stronger choose-rich pattern, but a weaker postreinforcement repetition pattern. Within this group, however, chicks with more exposure produced a stronger repetition pattern.

Such molecular patterns are a function in part of the schedules of reinforcement. Our results support a recent suggestion that independent scheduling facilitates positive recency: the repetition of reinforced responses (Davison & Baum, 2007; also see Bailey & Mazur, 1990; Schneider & Davison, 2006). On unusually rich schedules such as those in this study, postreinforcement repetition on the lean side contributed to suboptimal performance. The relationship between such patterns and the molar phenomenon of matching is an active area of research (e.g., Davison & Baum, 2000; Schneider, 2008).

What may have been most surprising about our results was the immediate emergence of these sequential patterns in so many of the chicks at such a young age. Might matching itself be considered ''innate,'' as Gallistel et al. (2007) suggested? That is, once the basic capacities for reinforcement and temporal sensitivity are present, might matching follow directly as a subsidiary effect–perhaps based on a kind of underlying ''program,'' as suggested by these researchers? While our results indicate that neonates can track simultaneous consequence rates to some extent, they appear to require further experience to develop the higher sensitivities typically seen in adults. Given the overall data set–including chicks that moved away from rather than toward matching during training, the developmental progression, and the failure of even the highest-responding chicks to achieve high-sensitivity matching–we suggest that our data favor instead the possibility that matching does require a learning process of its own. We note in addition that the developmental dynamics of matching in altricial animals may be different than what we observed in these precocial birds.

REFERENCES

Anderson, K. G., Velkey, A. J., & Woolverton, W. L. (2002). The generalized matching law as a predictor of choice between cocaine and food in rhesus monkeys. *Psychopharmacology, 163*, 319–326.

Anderson, K. G., & Woolverton, W. L. (2000). Concurrent variable-interval drug self-administration and the generalized matching law: A drug-class comparison. *Behavioural Pharmacology, 11*, 413–420.

Bacon, W. E., & Wong, I. G. (1972). Reinforcement value of electrical brain stimulation in neonatal dogs. *Developmental Psychobiology, 5*, 195–200.

Bailey, J. T., & Mazur, J. E. (1990). Choice behavior in transition: Development of preference for the higher probability of reinforcement. *Journal of the Experimental Analysis of Behavior, 53*, 409–422.

Bakeman, R., & Gottman, J. M. (1986). *Observing interaction: An introduction to sequential analysis.* Cambridge: Cambridge University Press.

Barnes, G. W., & Baron, A. (1961). Stimulus complexity and sensory reinforcement. *Journal of Comparative and Physiological Psychology, 54*, 466–469.

Belke, T. W., & Belliveau, J. (2001). The generalized matching law describes choice on concurrent variable-interval schedules of wheel-running reinforcement. *Journal of the Experimental Analysis of Behavior, 75*, 299–310.

Borchelt, P., & Ringer, R. K. (1973). Temperature regulation development in bobwhite quail (*Colinus virginianus*). *Poultry Science, 52*, 793–798.

Caron, R. F., & Caron, A. J. (1968). The effects of repeated exposure and stimulus complexity on visual fixation in infants. *Psychonomic Science, 10*, 207–208.

Casey, M. B., & Lickliter, R. (1998). Prenatal visual experience influences the development of turning bias in bobwhite quail chicks (*Colinus virginianus*). *Developmental Psychobiology, 32*, 327–338.

Cliffe, M. J., & Parry, S. J. (1980). Matching to reinforcer value: Human concurrent variable-interval performance. *Quarterly Journal of Experimental Psychology, 32*, 557–570.

Davison, M., & Baum, W. M. (2000). Choice in a variable environment: Every reinforcer counts. *Journal of the Experimental Analysis of Behavior, 74*, 1–24.

Davison, M., & Baum, W. M. (2007). Local effects of delayed food. *Journal of the Experimental Analysis of Behavior, 87*, 241–60.

Davison, M., Krägeloh, C. U., Fraser, M., & Breier, B. H. (2007). Maternal nutrition and four-alternative choice. *Journal of the Experimental Analysis of Behavior, 87*, 51–62.

Davison, M., & McCarthy, D. (1988). *The matching law: A research review.* Hillsdale, NJ: Erlbaum.

Delsaut, M. (1991). Influence of nonobvious learning on the development of the approach response in chicks (*Gallus gallus*). *International Journal of Comparative Psychology, 4*, 239–251.

Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior, 5*, 529–530.

Flory, G. S., Langley, C. M., Pfister, J. F., & Alberts, J. R. (1997). Instrumental learning for a thermal reinforcer in 1-day-old rats. *Developmental Psychobiology, 30*, 41–47.

Gallistel, C. R., King, A. P., Gottlieb, D., Balci, F., Papachristos, E. B., Szalecki, M., et al. (2007). Is matching innate? *Journal of the Experimental Analysis of Behavior, 87*, 161–199.

Hollard, V., & Davison, M. C. (1971). Preference for qualitatively different reinforcers. *Journal of the Experimental Analysis of Behavior, 16*, 375–380.

Hutton, L., Gardner, E. T., & Lewis, P. (1978). Matching with a key-peck response in concurrent negative reinforcement schedules. *Journal of the Experimental Analysis of Behavior, 30*, 225–230.

Kollins, S. H., Lane, S. D., & Shapiro, S. K. (1997). Experimental analysis of childhood psychopathology: A laboratory matching analysis of the behavior of children diagnosed with Attention-Deficit Hyperactivity Disorder (ADHD). *The Psychological Record, 47*, 25–44.

Loewenstein, Y., & Seung, H. S. (2006). Operant matching is a generic outcome of synaptic plasticity based on the covariance between reward and neural activity. *Proceedings of the National Academy of Sciences, 103*, 15224–15229.

Mazur, J. E. (2001). Hyperbolic value addition and general models of animal choice. *Psychological Review, 108*, 96–112.

McCall, R. B., & Kagan, J. (1967). Attention in the infant: Effects of complexity, contour, perimeter, and familiarity. *Child Development, 38*, 939–952.

Platt, M. L., & Glimcher, P. W. (1999). Neural correlates of decision variables in parietal cortex. *Nature, 400*, 233–238.

Rachlin, H., Green, L., & Tormey, B. (1988). Is there a decisive test between matching and maximizing? *Journal of the Experimental Analysis of Behavior, 50*, 113–123.

Satinoff, E., & Hendersen, R. (1977). Thermoregulatory behavior. In W. K. Honig, & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 153–173). Englewood Cliffs, NJ: Prentice-Hall.

Schneider, S. M. (2003). Evolution, behavior principles, and developmental systems: A review of Gottlieb's *Synthesizing nature-nurture: Prenatal roots of instinctive behavior. Journal of the Experimental Analysis of Behavior, 79*, 137–152.

Schneider, S. M. (2007). The tangled tale of genes and environment: Moore's *The dependent gene: The fallacy of. "nature vs. nurture." The Behavior Analyst, 30*, 91–105.

Schneider, S. M. (2008). A two-stage model for concurrent sequences. *Behavioural Processes, 78*, 429–441.

Schneider, S. M., & Davison, M. (2005). Demarcated response sequences and the generalised matching law. *Behavioural Processes, 70*, 51–61.

Schneider, S. M., & Davison, M. (2006). Molecular order in concurrent response sequences. *Behavioural Processes, 73*, 187–198.

Schneider, S. M., & Lickliter, R. (2009). Operant generalization of auditory tempo in quail neonates. *Psychonomic Bulletin & Review, 16*, 145–149.

Schneider, S. M., & Lickliter, R. (2010). Operant generalization in quail neonates after intradimensional training: Distinguishing positive and negative reinforcement. *Behavioural Processes, 83*, 1–7.

Schofield, G., & Davison, M. (1997). Nonstable concurrent choice in pigeons. *Journal of the Experimental Analysis of Behavior, 68*, 219–232.

Shull, R. L., & Pliskoff, S. S. (1967). Changeover delay and concurrent schedules: Some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior, 10*, 517–527.

Silberberg, A., Thomas, J. R., & Berendzen, N. (1991). Human choice on concurrent variable-interval variable-ratio schedules. *Journal of the Experimental Analysis of Behavior, 56*, 575–584.

Sugrue, L. P., Corrado, G. S., & Newsome, W. T. (2004). Matching behavior and the representation of value in the parietal cortex. *Science, 304*, 1782–1787.

Weiss, B., & Laties, V. G. (1961). Behavioral thermoregulation. *Science, 133*, 1338–1344.

Wearden, J. H., & Burgess, I. S. (1982). Matching since Baum (1979). *Journal of the Experimental Analysis of Behavior, 38*, 339–348.

Williams, B. A. (1988). Reinforcement, choice, and response strength (pp. 167–244). In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Steven's handbook of experimental psychology* (2nd ed.), *Vol 2. Learning and cognition*. NY: Wiley.

Received: May 10, 2010
Final Acceptance: July 15, 2010