

Salem State University
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Delay Discounting and Polydipsia in Spontaneously Hypertensive and Lewis Rats

A Thesis in Behavior Analysis

By

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Abstract

The choices made by Spontaneously Hypertensive Rats (SHRs) were compared with those made by the Lewis rats (LEWs) responding to a concurrent-chains procedure varying the delay to the larger later reinforcement (LLR). Impulsive choice was measured in conditions where a bottle of water was or was not available in the choice situation. Both strains produced discounting functions with proportions of choice decreasing with increasing delay to the LLR. At the beginning of training the LEWs made more impulsive choices than the SHR, but late in training both strains produced similar discounting rates suggesting same levels of impulsivity. Sensitivity of choice to the magnitude of the LLR also increased with extended training in the choice situation. Adding the bottle of water to the choice situation did not affect the impulsive choices made by the SHRs and the LEWs, but both strains developed polydipsia indicating that it was induced by food, with the SHRs drinking substantially more water than the LEWs. Licking mostly occurred in blackouts and before starting the choice cycles, showing a tendency to decrease in the initial and terminal links of the concurrent-chains procedure. Licking persisted when the water was removed from the choice situation, but the spout of the bottle was available for the rats to lick, indicating that water was not necessary to maintain licking. Overall, these findings support the laws of allocation, induction, and covariance (Baum, 2018a, 2018b).

Key words: Choice, impulsivity, delay-discounting, polydipsia, SHRs, LEWs.

In the study of human-patterns of behavior described as “impulsive,” impulsivity is defined as a “predisposition toward rapid unplanned reactions to internal or external stimuli” (Bakhshani, 2014). Behaviors such as short attention span, deficiencies in the inhibitory control of responses, hypersensitivity to delayed consequences, and hasty decision-making characterize impulsivity leading research to separate motor impulsivity from cognitive impulsivity (Evenden, 1999). Motor impulsivity is an excess of overall physical activity (Winstanley, Eagle, & Robbins, 2006), and cognitive impulsivity involves hasty decision-making (Brunner & Hen, 1997) occurring in situations where the organism chooses between a small-instant consequence called the smaller-sooner reinforcer (SSR) and a large-delayed consequence termed the larger-later reinforcer (LLR). A tendency to choose the former over the latter indicates impulsive choice (Ainslie, 1974), and choosing the LLR more often than the SSR defines a self-controlled choice (Louge, 1988).

When there is no difference in temporal delays (i.e., how long until a reward is delivered) organisms typically choose a larger reward over a smaller reward. As the delay to the LLR increases, the organism’s preference for the LLR switches to the SSR indicating that the value of the LLR (its efficacy) is discounted as a function of an increasing delay to receive it (e.g., Aparicio, Elcoro, & Alonso-Alvarez, 2015; Aparicio, Hennigan, Mulligan, & Alonso-Alvarez, 2019; Aparicio, Malonson, & Hensley, 2020). The behavioral process by which the efficacy of the LLR decreases as a function of the increasing delay to get it, is termed delay discounting (Myerson & Green, 1995). Mazur’s (1987) hyperbolic-decay model effectively describes delay discounting as follows.

$$V = \frac{A}{1+kD} \cdot \tag{1}$$

Where V stands for the current value of the LLR (its effectiveness at the time of choice), A is the amount of the LLR, D is the delay to obtain it, and k is a free parameter estimating how fast its

value decays with increasing D . The larger the value of k , the higher the rate discounting the LLR suggesting high levels of impulsive choice (i.e., Aparicio, Hughes, & Pitts, 2013; Aparicio et al., 2015; 2019). The efficacy of the hyperbolic-decay model in describing delay discounting data produced by non-human animals, is noteworthy (e.g., Aparicio et al., 2013; Aparicio et al., 2015, 2019; Farrar et al., 2003; Mazur, 2012; Green et al., 2007; Stein, et al., 2012).

Discrete trials procedures arranging forced trials to sample both the LLR and SSR, and free trials to choose between the LLR and SSR, are used to analyze impulsive choice (Evenden and Ryan, 1996). Free and forced trials used in adjusting amounts of reinforcers (Mazur, 1987) and adjusting delay procedures successfully examined delayed reinforcement (Mazur, 1998) and hyperbolic discounting (Mazur & Biondi, 2009). The advantages and disadvantages of using discrete trials to analyze impulsive choice were reviewed by Madden and Bickel (2010) warranting the use of other methods (e.g., concurrent-chains procedures) to analyze impulsive choice (Aparicio et al., 2015). Concurrent-chains procedures have been successfully used to examine impulsive choice in inbred strains of Spontaneously Hypertensive (SHR), Wistar Kyoto (WKY), Lewis (LEW), and Fischer 344 (F344) rats as subjects (e.g., Aparicio et al., 2013, 2015, 2019). With the WKY as the normotensive control for the SHR (Okamoto, 1969) and the F344 as the neurochemical control for the LEW (Chaouloff, et al., 1995), research on delay discounting shows that the LEW chooses more impulsively than the F344 (Aparicio et al., 2013) and the SHR makes more impulsive choices than the WKY (Aparicio et al., 2019).

The rationale for studying impulsive choice in SHRs and LEWs is that both strains of rats display behaviors characterizing the Attention Deficit/Hyperactivity disorder (ADHD) such as inattention, impulsivity, learning difficulties, and hyperactivity affecting human children and adults (Farrar et al., 2003; Fox et al., 2008). Recent studies suggesting the LEW rat might be an

appropriate control for the SHR rat (Hensley, 2021), found that early in training the LEW made more impulsive choices than the SHR. At the end of training, however, the SHR chosen more impulsively than the LEW indicating that impulsive choice in the SHR increases substantially with its experience in the choice situation (i.e., seminal to Aparicio et al., 2019). Yet, in Hensley's study, choosing between the LLR and SSR some individuals of each strain produced steep discounting functions and other individuals smooth discounting functions, allowing between strains comparisons of impulsive choice based on high- and low-discounting rates supporting the idea that LEW is an appropriate control for the SHR. The present study extended the generality of these findings examining the relation previously found between impulsive choice and polydipsia (Ibias & Pellón, 2011, 2014) in two models of ADHD, the SHR rat and the LEW rat.

Polydipsia is the behavior of drinking an excessive amount of water during the interval between consecutive food deliveries (Falk, 1961). Because it occurs on both response dependent fixed interval (FI) and response-independent fixed time (FT) schedules (Falk, 1966, 1969), polydipsia is known as schedule-induced polydipsia (SIP), or an adjunctive behavior (Falk, 1971). The term adjunctive behavior, however, refers to a variety of activities (e.g., eating nonfood material, wheel running, and aggression) induced in nonhuman animals (e.g., rats and pigeons) by intermittent schedules of reinforcement (Falk, 1970). Adjunctive behaviors take some time to develop (e.g., Reynierse & Spainer, 1968), occur during timeout periods (Wüttke, 1970), and following brief stimulus presentations on second-order interval schedules (Rosenblith, 1970); Segal et al (1965) show they occur following each response on a differential reinforcement of low rates schedule, and later in the interval of a long FT schedule (Segal, Oden, & Deadwyler, 1965). Keehn and Colotla (1970) indicate these behaviors occurred when the last food-pellet, out of a number of food-pellets, is delivered at the end of a FI schedule. Adjunctive behaviors are interim

activities occurring in the post-reinforcement time, when the reinforcement is not available and terminal responses are not occurring (Staddon & Simmelhag, 1971). Induction is the process accounting for interim activities and some effects on operant activities (Segal, 1972). It replaces the notions of reinforcement and strength (Baum, 2012), where reinforcers induce the operant activities that they maintain (Baum, 2021). Induction is an important concept for a multiscale view of choice (Baum, 2018b) analyzing the organism's activities according to the laws of allocation, induction, and covariance (Baum, 2018a). Briefly, the law of allocation asserts that activities compete with one another for time, where competition is crucial to understand behavior allocation (Baum, 2018a, 2018b). The law of induction uses the notion of a phylogenetical important event (PIE) to describe any event determining the organism's likelihood of surviving and reproducing (Baum, 2021). Additionally, the law of covariance addresses the organism's sensitivity to events covarying in the environment; it determines which activities are induced by PIEs causing induced activities to increase and non-induced activities to fade (Baum, 2021). Activities induced and maintained by PIEs are operant activities that covary with PIEs, and stimuli that covary with PIEs become "proxies" of the PIEs and induce activities like those induced by PIEs (Baum, 2021). For example, food delivered contingent upon responding induces the operant activity on which food depends, the operant activity is maintained by a feedback loop where food (PIE) induces the activity, and the activity produces the food (Baum, 2021). Both noncontingent and contingent food presentations induce adjunctive behaviors (Falk, 1971, 1977; Staddon, 1977) that might compete with operant activities (Baum & Aparicio, 2020; Gutierrez & Pellón, 2019).

One aim of the present study is to show that food induces polydipsia in a choice situation where pressing on two levers, one producing the SSR and the other the LLR, is maintained in conditions that vary the delay to deliver the LLR, while holding constant the delay to deliver the

SSR. Another aim is to confirm that inbred strains of SHR and LEW rats learn to choose impulsively with extended training in the choice situation, and if it will happen regardless of whether the rats develop polydipsia in the current choice situation producing the LLR and SSR. The last aim is to extend the generality of findings showing that the LEW rat is an appropriate control for the SHR. At the beginning of training the LEW rats are expected to produce higher discounting rates than the SHR rats, but this between strain differences in discounting rate should disappear with extended training in a choice situation, with both strains discounting the LLR with similar rates at the end of the study.

Method

Subjects

Sixteen inbred male rats, 8-SHR and 8-LEW (Charles River, Wilmington, MA), between 120-150 days old, were the subjects. All subjects had experience on auto-shaping procedures establishing the acquisition and maintenance of lever pressing (Aparicio et al., 2020). They were housed individually in plastic cages with water permanently available in a room maintaining a light dark cycle of 12:12 (lights on at 07:00) and controlling the temperature (ranging from 68 to 72 degrees F). The rats were fed with 10 g (+/- 2 g) of Purina Chow (Mazuri®) 20 minutes after each experimental session maintaining a regimen of food restriction. At the beginning of the experiment the weights of the SHRs ranged from 348 to 382 g (M = 363 g) and those of the LEWs from 292 to 310 (M = 303 g). When the experiment ended the weights of the SHRs ranged from 297 to 371 g (M = 340 g) and the weights of the LEWs from 372 to 405 g (M = 397 g). Sessions were conducted daily at same time (12:00 PM).

Apparatus

Eight modular chambers (E10-11R TC) for rats, each measuring 30 cm x 33 cm x 25 cm (Colbourn Instruments®), were used. Each chamber had two retractable levers (E23-17RA), 3.3 cm x 1.5 cm, mounted on the front wall 6 cm above the floor. The mechanism for the extension and retraction of the levers took approximately 0.1 s. A third nonretractable lever was centered on the back wall of each chamber 6 cm above the floor. All levers required a force of 0.2 N to be operated. A 24-V DC stimulus light (H11-03R) was placed 3.5 cm above each retractable lever. One 24-V DC house light (H11-01R) centered of the back wall of each chamber, 19 cm above the non-retractable lever, provided the illumination of the chamber. A dry-food dispenser (H14-23R) located behind the front wall of the chamber, delivered 45-mg grain-based pellets (BioServ®, F0165) into a 3 cm x 4 cm food cup (E14-01R) centered between the left and right retractable levers, 4.5 cm from the left lever and 4.5 cm from the right lever at 2 cm from the floor. A white noise generator (E12-08) was connected to a 2.6 cm x 4.0 cm speaker (H12-01R) placed on the back wall of each chamber at 20 cm from the floor, 1 cm from the left sidewall and 1 cm below the ceiling, to deliver a continuous white noise 20 kHz (+/- 3 dB) in the chamber. A photo-operandum buffer (H20-93) attached to a second hopper (E24-01) mounted on the back wall of the chamber, 2.6 cm above the floor and 7 cm from the center of the nonretractable lever, recorded contacts (licks) to the metal tube of a bottle containing tap water (100 ml). Two computers each linked to 4-chambers using Habitest Lincs (H02-08), delivered the stimuli and recorded responses executing Colbourn Instruments® software (Graphic State Notation, V 3.03) at a 0.01-s resolution.

Procedure

All rats were directly exposed to a concurrent-chains procedure comprising six delay components (0.1, 5, 10, 20, 40, 80 s) selected and presented in random order during the session. Each delay component arranged 10-choice cycles followed by a 1-min blackout to choose a

different delay component. Each choice cycle started with the illumination of the house light and the front levers retracted from the chamber. A single response on the back-nonretractable lever turned off the house light, extended the front levers into the chamber, and turned on the lights above the levers signaling the beginning of the initial link of the concurrent-chains procedure. Choice was measured in the initial link with the allocation of responses to the extended levers associated with two random interval (RI) schedules averaging 11 s each. The RI schedules were concurrently available in the initial link (conc RI 11 s RI 11 s) arranging entries to two terminal links. One RI schedule operated on the left or SS lever and the other RI operated on the right or larger later (LL) lever. When the RI associated with the smaller sooner (SS) lever arranged an entry to one terminal link, the LL lever was retracted from the chamber and the light above it turned off. One response on the active SS lever produced one food-pellet (i.e., the SSR) with a negligible delay (0.1 s). The delivery of the SSR caused the active SS lever to retract from the chamber, turning off the light above the lever and turning on the house light. The rat moved from the front wall to the back wall of the chamber to press the back-nonretractable lever to start another cycle. In the cycles where the RI schedule associated with the LL lever arranged an entry to the other terminal link, the SS lever was retracted from the chamber and the light above it turned off. One response on the active LL lever, started a fixed time (FT) schedule (0.1, 5, 10, 20, 40, or 80 s) delaying the delivery of four-food pellets (i.e., the LLR). The LL lever was not retracted from the chamber during the delay, preventing its retraction to signal the delay to the LLR. Responses on the LL lever during the delay to the LLR had no scheduled consequences, the only factor affecting choice in the initial link was the delay to deliver the LLR. The delivery of the LLR caused the active LL lever to retract from the chamber, turning off the light above it, and turning on the house light. The next choice cycle started with the rat pressing the back-nonretractable lever, re-

stablishing the above conditions. After ten food deliveries, 5-SSR with the SS lever and 5-LLR with the LL lever, all lights were turned off and the levers were retracted from the chamber starting a 1-min blackout. Sessions ended after 60-choice cycles were completed (10-choice cycles for each delay component), or 60 minutes elapsed, whichever happened first. For four rats of each strain, the left-retractable lever produced the LLR and the right-retractable lever the SSR. These conditions were reversed for the other four rats of each strain, the left-retractable lever produced the SSR and the right-retractable lever the LLR, controlling for a possible bias of the rats for one lever over the other lever.

The concurrent-chains procedure was implemented in three conditions differing from one another in terms of whether or not a bottle with water was always available in the choice situation for the rats to drink through the session. The first condition was a no-water condition (NW₁) lasting 150 consecutive sessions. The second condition followed, a water condition (W), where a bottle was filled with 100 ml of tap water and placed into the chamber at the beginning of each session. The water was always available in the choice situation for 150 consecutive sessions. At the end of each session, the bottle was removed from the chamber to measure the residual of water and compute the difference between the 100-ml of water available at the beginning of the session and the water that the rat consumed during the session. The last condition was a re-determination to no-water (NW₂), the bottle with water was removed from the chamber, leaving only the metal tube of a bottle connected to the photo-operandum buffer recording licks during the session. The NW₂ condition lasted 90 consecutive sessions that were enough for choice to show stability.

Data Analysis

The data from all sessions of each condition (NW₁, W, and NW₂) were organized in blocks of 15 sessions each and used for data analysis. The data were sorted and separated by delay

component, counting the total number of initial-link responses that each rat emitted on the LL and SS levers. For each individual and the group of rats within strain, the responses emitted on the SS and LL levers were used to compute the proportions of LL choice ((LL responses / (LL responses + SS responses)). Eq. 1 provided nonlinear curve fitting to proportions of LL choices, where the parameter A was not assumed to be 1.0 LL choice at the y-intercept. To compute the empirical area under the discounting curve (AUC), the delays to the LLF and the proportion of responses associated with the delays were normalized. Each delay to the LLF was expressed as a proportion of the maximum delay to the LLF (0.1/80, 5/80, 10/80, 20/80, 40/80, and 80/80), and each proportion of responses was expressed as a proportion of that associated with the shortest delay to LLF. Then, Myerson's et al (2001) technique was implemented with Excel (Microsoft®) as follows.

$$(x_2 - x_1) [(y_1 + y_2) / 2] \tag{2}$$

Where x_1 and x_2 are consecutive delays, and y_1 and y_2 proportions of responses associated with these delays. For all normalized delays and the proportions of responses associated with them, the sum of these computations is the area under the empirical discounting curve.

A 4-parameters logistic (4PL) nonlinear regression model was used to generate lines of best fit to the data of water consumed during the session and number of licks to the bottle of water; it is formally expressed as follows:

$$y = \frac{A_1 - A_2}{1 + (x/x_0)^p} + A_2, \tag{3}$$

where A_1 is the minimum asymptote or initial value estimated for either k (discounting rate) or s (sensitivity), p is the power or slope of the curve, x_0 the inflection point where the curvature changes direction, and A_2 the maximum asymptote or final value estimated for either k or s .

Between-strains differences in dependent variables and parameters estimated with Eq. 1 were examined using nonparametric statistical methods, because two main requirements of the analysis of variance, normality and equal error variance, were not fulfilled, and the small size of the samples did not allow for confident assertions of the main assumptions. Origin® provided curvilinear fitting, linear fitting, and nonparametric statistical tests at the alpha level of 0.05.

Results

Condition NW₁

For the choices that the SHRs and LEWs made in the NW₁ condition, computations of the proportion of LL choice ($(LL/(LL+SS))$) are plotted in Figure 1 as a function of the delay (s) to deliver the LLR. From left to right and top to bottom, the graphs are organized from block 1 to block 10 of sessions. Unfilled circles with error bars stand for mean proportions of LL choice computed for the group of the SHRs and unfilled squares with error bars for mean proportions of LL choice corresponding to the group of the LEWs. The solid (SHRs) and broken (LEWs) lines are the best fits of Eq. 1 to mean proportions of LL choice. Estimates of discounting rate for the discounting functions produced by the LEWs (k_{LEW}) and SHRs (k_{SHR}) appear on the upper right-hand corner of each graph. Table 1 shows the resulting parameters from fits of Eq. 1 to mean proportions of choice produced by the SHRs and LEWs.

All graphs show that the proportion of LL choice decreased with the increasing delay to the LLR. Eq. 1 fitted mean data produced by the SHRs and LEWs well, accounting for changes in the proportion of LL choice that occurred as a function of increasing delay to the LLR; for the discounting functions produced by the SHRs R^2 ranged from .894 to .995 ($M = .970$) and from .754 to .996 ($M = .958$) for the discounting functions produced by the LEWs (see table 1).

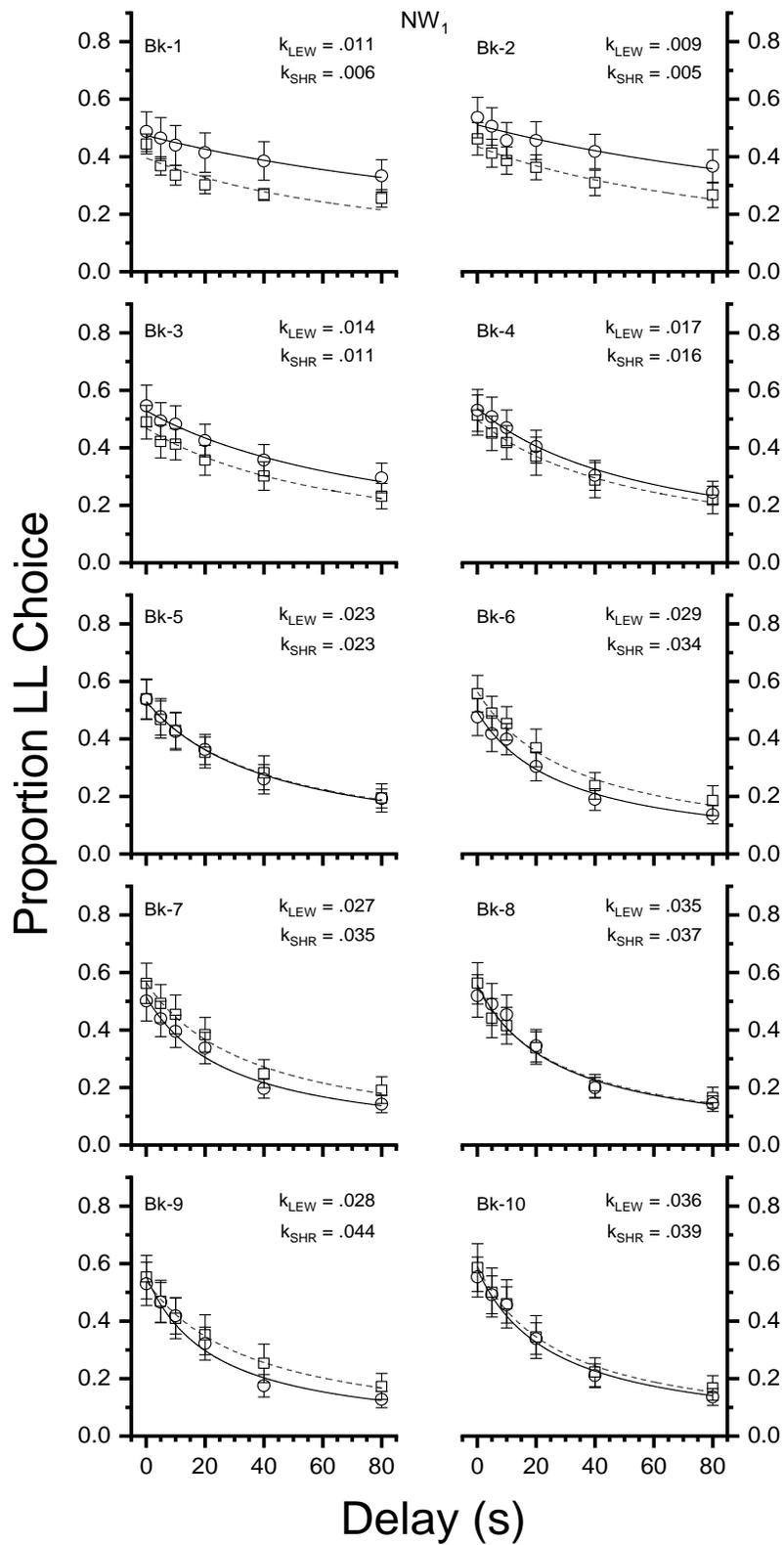


Fig. 1. For the SHRs and LEWs, mean proportions of LL choice against blocks of session.

Table 1.
Hyperbolic-decay model, resulting parameters (NW₁).

Block	<i>A</i>		<i>k</i>		<i>R</i> ²	
	SHR	LEW	SHR	LEW	SHR	LEW
1	0.474	0.396	0.006	0.011	0.968	0.754
2	0.511	0.436	0.005	0.009	0.894	0.942
3	0.529	0.469	0.011	0.014	0.979	0.978
4	0.538	0.498	0.016	0.017	0.984	0.991
5	0.532	0.528	0.023	0.023	0.995	0.994
6	0.494	0.565	0.034	0.029	0.979	0.983
7	0.516	0.565	0.035	0.027	0.978	0.985
8	0.558	0.549	0.037	0.035	0.965	0.971
9	0.558	0.542	0.044	0.028	0.975	0.996
10	0.582	0.592	0.039	0.036	0.985	0.986
Mean	0.529	0.514	0.025	0.023	0.970	0.958

In blocks 1 to 4, the LEWs produced higher discounting rates (.011, .009, .014 and .017, respectively) than the SHRs (.006, .005, .011, .016, respectively). In block 5, however, the discounting rates produced by the LEWs ($k = .023$) were similar to those produced by the SHRs ($k = .023$). Blocks 6 to 10 show that the discounting rates produced by the LEWs increased from .027 to .036 ($M = .031$) and those produced by the SHRs from .034 to .044 ($M = .038$). Sensitivity of choice to the magnitude of the LLR (A in Eq. 1) increased with increasing blocks of sessions, for the data produced by the SHRs estimates of A increased from .474 to .582 ($M = .529$) and from .396 to .592 ($M = .514$) for the data produced by the LEWs.

Estimates of k (top graphs) and A (bottom graphs) computed with the data produced by the individuals of each strain are plotted in Figure 2 as a function of blocks of sessions. The left graphs show the data produced by the individual SHRs and the right graphs the data produced by the individual LEWs. Unfilled symbols stand for the data produced by the individuals and filled circles and squares with error bars for mean data produced by the group of SHRs and the group

of LEWs, respectively. The solid line is the best fit of Eq. 3 to mean data. The discounting rates increased with increasing blocks of sessions. The discounting rates produced by the individual SHR_s ranging from .001 to .080 (Mdn = .020), were like those ($U = 2815, p = 0.189$) produced by the individual LEW_s ranging from .002 to .149 (Mdn = .025). Eq. 3 fitted mean discounting rates produced by the SHR_s ($R^2 = .971$) and the LEW_s ($R^2 = .970$) well.

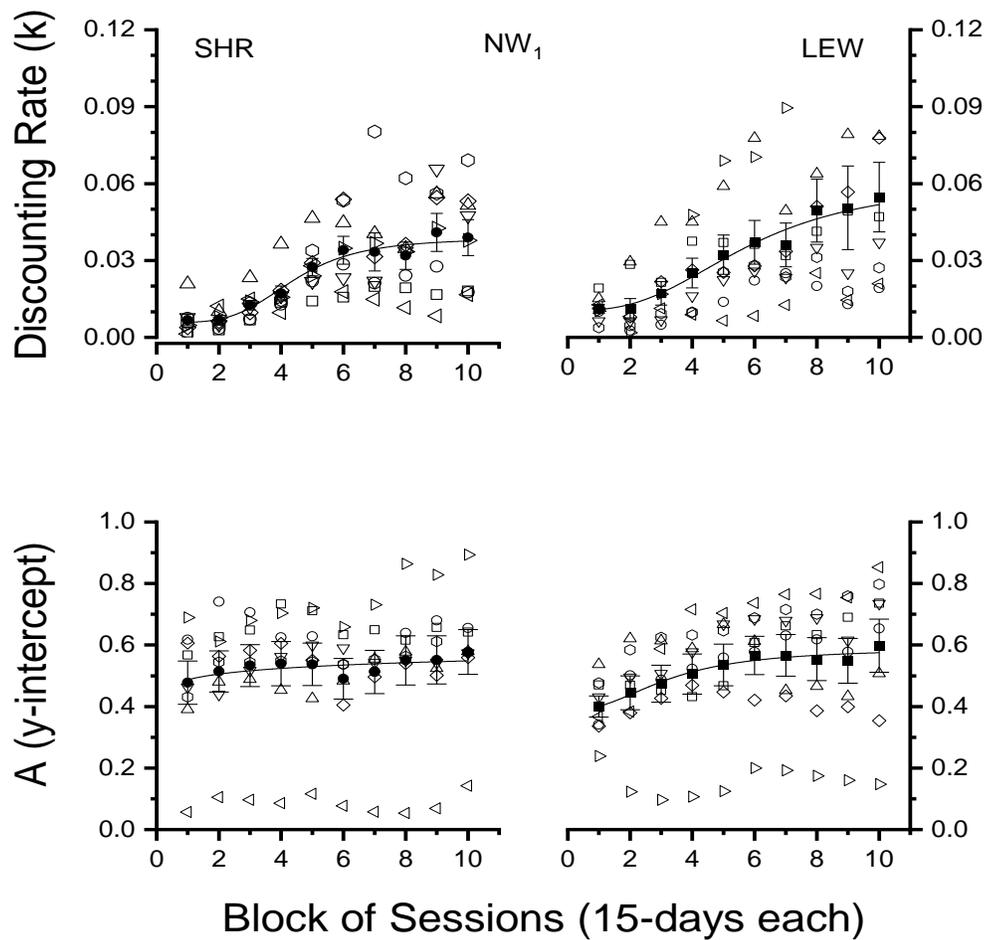


Fig. 2. For the SHR_s and LEW_s estimates of k and A as a function of blocks of sessions.

The starting (A_1) and ending (A_2) points of the curve fitting mean discounting rates produced by the SHR_s (.005 and .038, respectively) are smaller than those corresponding to the curve fitting mean discounting rates produced by the LEW_s (.010 and .061, respectively). Mean

discounting rates produced by the SHRs moved to asymptotical levels earlier in training ($x_0 = 4.40$) than mean discounting rates produced by the LEWs ($x_0 = 5.80$). Also, the discounting rates produced by the SHRs increased faster ($p = 4.09$) than those produced by the LEWs ($p = 2.80$).

Estimates of A for the discounting functions produced by the individual SHRs show values that either did not increase or increased little across block of sessions, contrasting with estimates of A for the discounting functions produced by the individual LEWs showing values that gradually increased across blocks of sessions. Estimates of A for the discounting functions produced by the individual SHRs ranging from .054 to .894 (Mdn = .563), were not significantly different ($U = 3317$, $p = 0.691$) from estimates of A for the discounting functions produced by individual LEWs ranging from .096 to .853 (Mdn = .548). Eq. 3 better fit estimates of A for the discounting functions produced by the LEWs ($R^2 = .967$) than fitting estimates of A for the discounting functions produced by the SHRs ($R^2 = .134$). The slope of the line fitting estimates of A for the data produced the LEWs ($p = 2.29$) is steeper than that fitting estimates of A for the data produced the SHRs ($p = 0.03$), indicating that sensitivity to magnitude of the LLR changed faster in the LEWs than in the SHRs. For the flat line fitting mean estimates of A for the discounting functions produced by SHRs, the parameters A_1 , A_2 , and x_0 resulted in aberrant values. In contrast, the starting ($A_1 = .387$) and ending ($A_2 = .588$) points of the line fitting mean estimates of A for the discounting functions produced by the LEWs, show that sensitivity to magnitude of the LLR increased across blocks and moved to asymptotical level early in training ($x_0 = 3.2$).

The next analysis used Meyerson's et al (2001) technique, which is a theory-free estimate of discounting, to compute the empirical area under the discounting curve (AUC). Computations of the AUC are expressed as proportions of 1, where values close to 1 indicate little discounting of the LLR and values close to 0 large discounting of the LLR. Estimates of the AUC are plotted

in Figure 3 against blocks of sessions. Unfilled symbols stand for AUCs computed with the data produced by the individuals and filled circles and squares with error bars for AUCs computed with the data produced by the group of SHRs (left graph) and the group of LEWs (right graph), respectively. For both strains, the graphs show that the AUC decreased across blocks of sessions. The AUCs computed with the choices made by the individual SHRs ranging from .32 to 1.0 (Mdn = .61), were not significantly different ($U = 3757$, $p = .057$) from the AUCs computed with the choices made by the individual LEWs ranging from .23 to .85 (Mdn = .56). The 4-parameter logistic equation (Eq. 3) fitted means of AUC produced by the SHRs ($R^2 = .966$) and LEWs ($R^2 = .911$) well. The starting point of the curve fitting AUCs produced by the SHRs ($A_1 = .831$) shows a higher value than the starting point of the curve fitting AUCs produced by the LEWs ($A_1 = .655$). The ending point of the curve fitting AUCs produced by the SHRs ($A_2 = .483$), is similar to the ending point ($A_2 = .439$) fitting AUCs produced by the LEWs. The AUCs produced by the LEWs decreased faster ($p = 4.40$) than those produced by the SHRs ($p = 3.20$). Yet, the AUC produced by the SHRs moved to asymptotical level ($x_0 = 3.45$) sooner than the AUC produced by the LEWs ($x_0 = 5.00$).

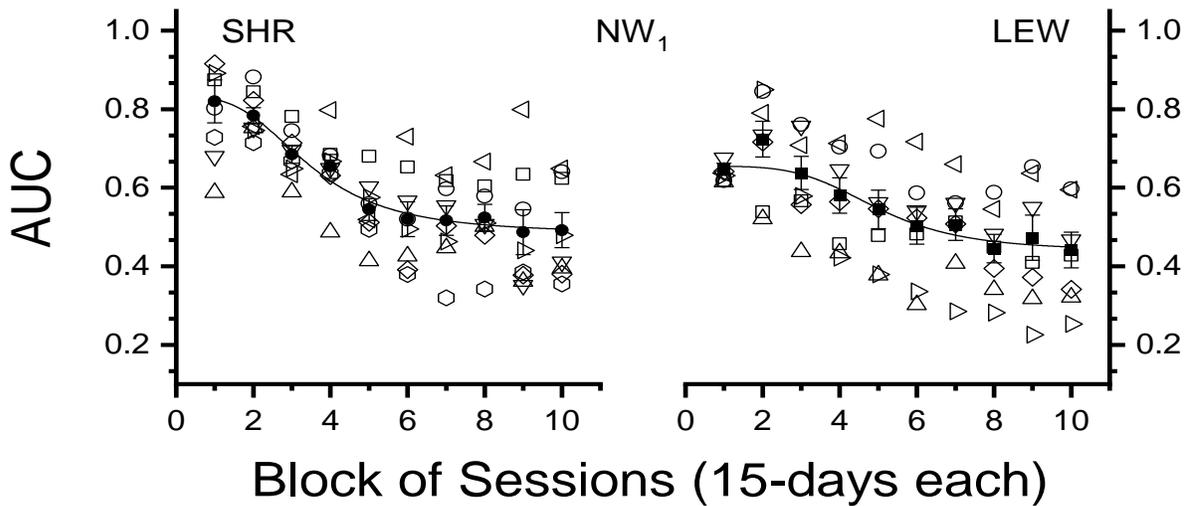


Fig. 3. AUCs computed with the choices made by the SHRs and LEWs. Solid line shows best fit to Eq. 3.

Condition W

Proportions of LL choice computed for the choices that the SHRs and LEWs made in the condition with access to water permanently available in the choice situation (W), are plotted in Figure 4 against the delay to the LLR (other details as in Figure 1). With the increasing delay to obtain the LLR, the rats' preference for the LLR gradually moved to preference for the SSR. The shape of the discounting functions produced by the SHRs is like that of the discounting functions produced by the LEWs; note that the line fitting the discounting functions produced by the SHRs is close to that fitting the discounting functions produced by the LEWs and in some blocks both fitting lines overlap across delays. Table 2 shows the resulting parameters from Eq. 1 fitting the mean proportion of choice produced by the SHRs and LEWs.

Table 2.
Hyperbolic-decay model, resulting parameters (W).

Block	<i>A</i>		<i>k</i>		<i>R</i> ²	
	SHR	LEW	SHR	LEW	SHR	LEW
1	0.651	0.569	0.040	0.029	0.964	0.977
2	0.670	0.596	0.039	0.032	0.987	0.980
3	0.707	0.581	0.045	0.032	0.980	0.960
4	0.700	0.586	0.042	0.032	0.973	0.979
5	0.695	0.598	0.041	0.037	0.975	0.974
6	0.692	0.599	0.041	0.039	0.974	0.977
7	0.686	0.596	0.044	0.033	0.957	0.991
8	0.685	0.612	0.048	0.039	0.971	0.994
9	0.686	0.610	0.037	0.043	0.975	0.992
10	0.665	0.631	0.036	0.045	0.972	0.996
Mean	0.684	0.598	0.041	0.036	0.973	0.982

The hyperbolic-decay model fitted the discounting functions produced by the SHRs and LEWs well, goodness of fit (R^2) for the discounting functions produced by the SHRs ranged from .957 to .987 (M = .973) and from .960 to .996 (M = .982) for the discounting function produced by

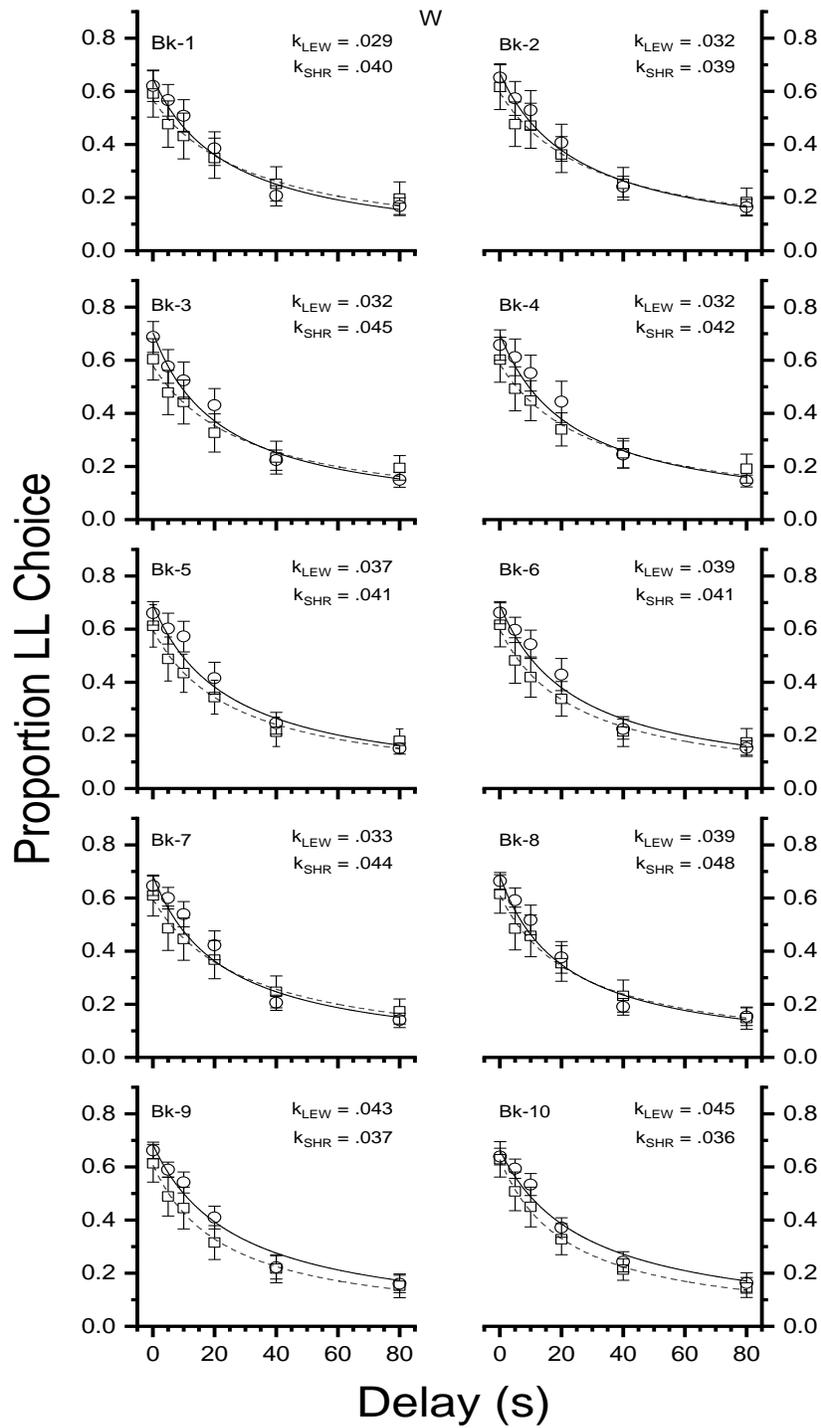


Fig. 4. For the water condition, mean proportions of LL choice against blocks of sessions.

the LEWs. The discounting rates produced by the SHRs changed little across blocks of sessions ($M = .041$), contrasting with the discounting rates produced by the LEWs that increased from .029 in block 1 to .045 in block 10 ($M = .036$). Estimates of A show that sensitivity of choice to the magnitude of the LLR increased with increasing number of blocks of sessions, the discounting functions produced by the SHRs generated estimates of A ranging from .651 to .707 ($M = .684$) and those produced by the LEWs estimates of A ranging from .569 to .631 ($M = .598$).

Estimates of discounting rate (k) and sensitivity to the magnitude of the LLR (A) for the choices that the individual SHRs and LEWs made with the water always available in the choice situation, are plotted in Figure 5 as a function of blocks of sessions. (Other details as in Figure 2). The top graphs show discounting rates produced by the individual LEWs that are slightly higher than the discounting rates produced by the individual SHRs, and the bottom graphs estimates of A for the choices made by LEWs that are slightly smaller than estimates of A for the choices made by the SHRs. Mann-Whitney tests, however, revealed that the discounting rates produced by the individual SHRs ranging from .018 to .122 (Mdn = .042) were not significantly different ($U = 2882$, $p = 0.278$) from the discounting produced by the individual LEWs ranging from .007 to .234 (Mdn = .043). Similarly, estimates of A for the choices made by the individual SHRs ranging from .286 to 1.00 (Mdn = .690), were not significantly different ($U = 3265$, $p = 0.826$) from estimates of A for the choices made by the individual LEWs ranging from .112 to .808 (Mdn = .711).

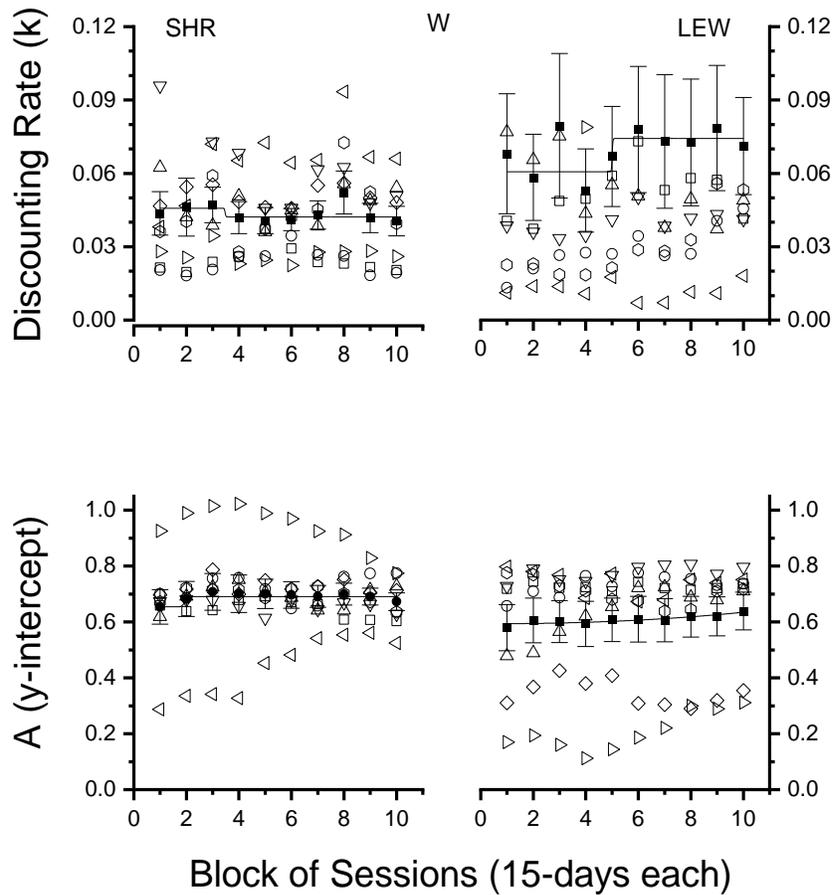


Fig. 5. For the water condition, estimates of k and A as a function of blocks of sessions.

The graphs in Figure 5 show that mean estimates of k and A (filled symbols) changed little across blocks of sessions. Eq. 3 fitting mean estimates of k and A for the choices made by the LEW's ($R^2 = .266$ and $.711$, respectively), did a better job than fitting mean estimates of k and A for the choices made by the SHRs ($R^2 = -.177$ and $.502$, respectively). The starting and ending points of the line fitting mean discounting rates produced by the LEWs, $A_1 = .060$ and $A_2 = .074$, respectively, were higher than those corresponding to the line fitting mean discounting rates produced by the SHRs, $A_1 = .046$ and $A_2 = .042$, respectively. Estimates of the inflection point revealed that mean discounting rates produced by the SHRs moved to an asymptotical level earlier in training ($x_0 = 3.47$) than mean discounting rates produced by the LEWs ($x_0 = 5.00$). The slopes

of the lines fitting mean discounting rates produced by the LEWs and SHRs, resulted in anomalous values ($p = 394$ and 265 , respectively). For the choices made by the SHR, the starting (A_1) and ending (A_2) points of the line fitting mean estimates of A were $.708$ and $.628$, respectively, and the inflection point of the curve ($x_0 = 9.0$), suggesting that the sensitivity of choice to the magnitude of the LLR moved to an asymptotical level late in training. The flat line fitting mean estimates of A for the discounting functions produced by LEWs resulted in aberrant values for parameters A_1 , A_2 , and x_0 (the fits did not converge after several iterations).

Computations of the AUC for the choices that the individual SHRs and LEWs made with the access to water permanently available in the choice situation, are plotted in Figure 6 against blocks of sessions. (Other details as in Figure 3).

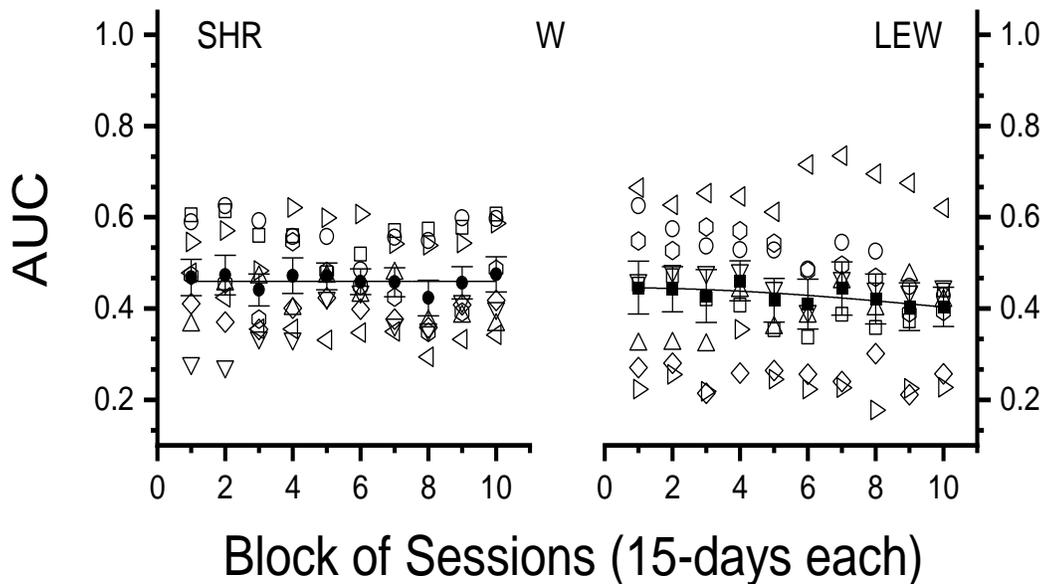


Fig. 6. For the water condition, estimates of AUC as a function of blocks of sessions. The filled symbols stand for mean values of AUC computed for the group of SHRs (circles) and the group of the LEWs (squares).

The graphs show small decreases in AUCs across blocks of sessions, and mean AUCs computed with the choices made by the SHRs ($M = .45, SE = .036$) are similar to mean AUCs computed with the choices made by the LEWs ($M = .43, SE = .052$). This result was confirmed with estimates of the AUC computed with the choices made by the individual SHRs, ranging from .27 to .63 ($Mdn = .45$), that were similar to ($U = 3647, p = .128$) the AUCs computed with the choices made by the individual LEWs, ranging from .18 to .73 ($Mdn = .44$). Eq. 3 fitting AUCs produced by the choices made by the SHRs and LEWs, generated poor values of R^2 (- .500 and .304, respectively) due to small changes in AUC that occurred across blocks of sessions.

The total volume of water (ml) that the group of the SHRs and the group of the LEWs consumed in the choice situation is plotted in Figure 7 against blocks of sessions. It shows that the SHRs' consumption of water across blocks of sessions, ranging from 3.9 to 17.1 ml ($Mdn = 14.4$),

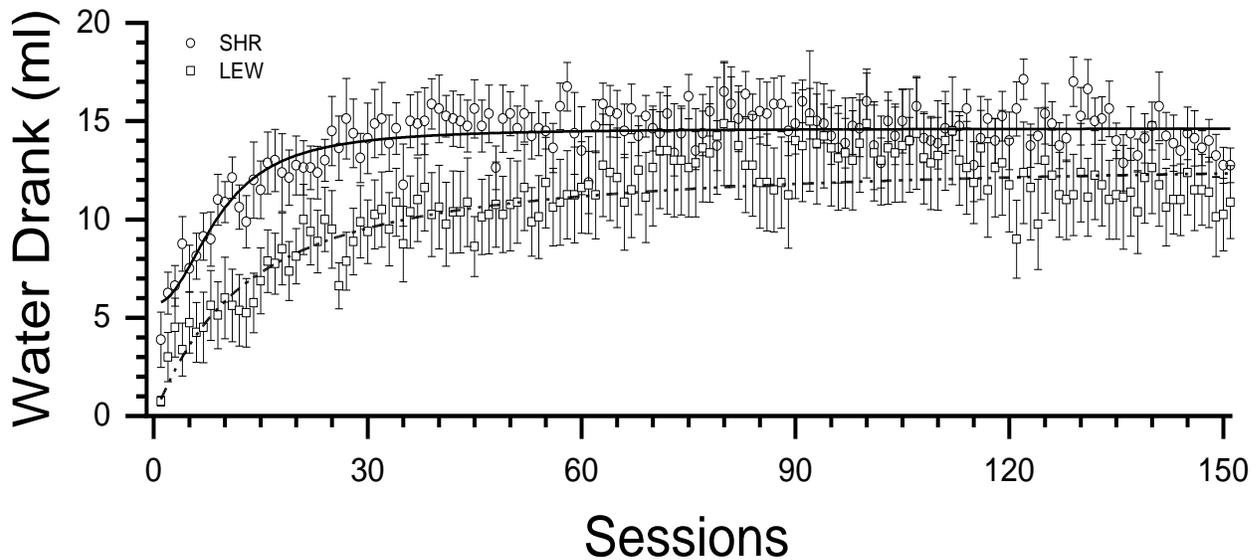


Fig. 7. For the SHRs (circles) and LEWs (squares) volume of water consumed (ml) in the choice situation as a function of across blocks of sessions.

was higher ($U = 20297$, $p = .000$) than the LEWs' consumption of water, ranging from .08 to 15.0 ml (Mdn = 11.4). Eq. 3 fitted the data of water consumption from the SHRs ($R^2 = .735$) and LEWs ($R^2 = .958$) well, accounting for changes in the consumption of water occurring as a function of increasing blocks of sessions. The starting and ending points of the line fitting the SHRs' consumption of water ($A_1 = 5.71$ and $A_2 = 14.63$) have values greater than those of the line fitting the LEWs' consumption of water ($A_1 = .071$ and $A_2 = 13.12$). The inflection point of the former line ($x_0 = 9.14$) is smaller than that of the latter line ($x_0 = 12.13$) indicating that the SHRs' consumption of water moved to asymptotical level earlier in training than the LEWs' consumption of water. Lastly, the slope of the line fitting the data from the SHRs is steeper ($p = 2.17$) than that fitting the data from the LEWs ($p = 1.1$), indicating faster changes in consumption of water for the SHRs than for the LEWs.

The next analyses looked at the number of licks to the spout of the bottle that occurred: (1) during the blackout periods separating the delay components, (2) before starting the initial link, (3) in the initial link when both levers were extended into the chamber, and (4) in the terminal link when only the LL lever was extended into the chamber during the delay to the LLR. The number of licks to the spout of the bottle during the blackout periods separating delay components, are plotted in Figure 8 against blocks of sessions. Generally, the LEWs emitted more licks to the spout of bottle during the blackout periods than the SHRs. The number of licks that the individual LEWs emitted across block of sessions, ranging from 28 to 17924 (Mdn = 5325) was significantly higher ($U = 2345$, $p = .004$) than the number of licks that the individual SHRs emitted across block of sessions, ranging from 173 to 8889 (Mdn = 3943).

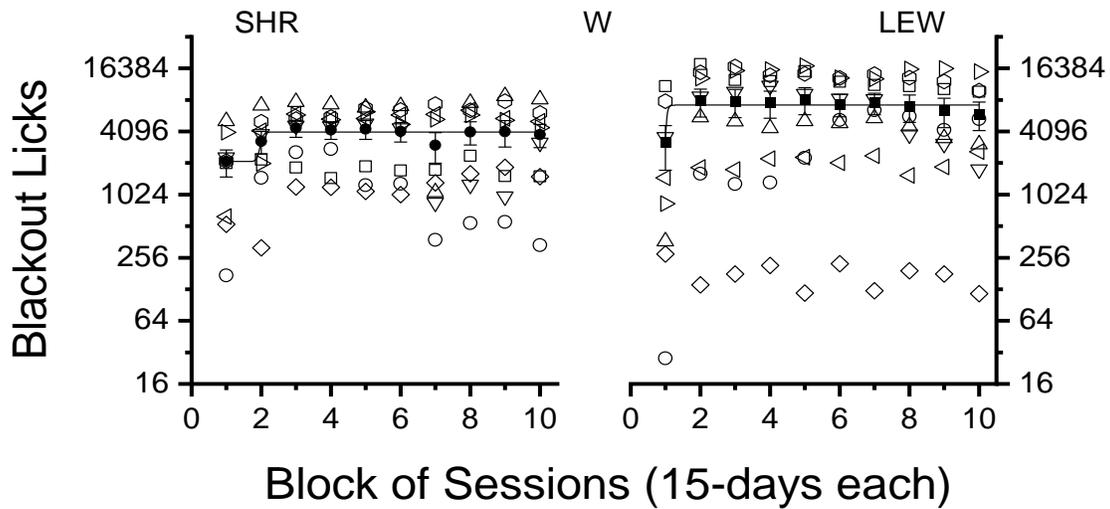


Fig. 8. Number of licks to a spout of a bottle containing water as a function of blocks of sessions. Note logarithmic scale base-2 on the y-axis. Unfilled symbols stand for the data of the individuals and filled circles and squares for the mean number of licks produced by the group of SHRs and the group of LEWs, respectively.

For the mean number of licks to the spout of the bottle that the group of the LEWs and the group of SHRs emitted during the blackout periods, Figure 8 shows few changes across blocks of sessions. Eq. 3 fitted the mean number of licks emitted by the LEWs ($R^2 = .779$) and SHRs ($R^2 = .756$) well, accounting for changes in the number of licks that occurred as a function of increasing blocks of sessions. The inflection point of the curve fitting the data from the LEWs ($x_0 = 0.86$) is smaller than that fitting the data from the SHRs ($x_0 = 1.98$), indicating that the LEWs' number of licks moved to asymptotical level earlier in training than the SHRs' number of licks. Yet, the slope of the line fitting the mean number of licks emitted by the SHRs is steeper ($p = 42.2$) than that of the line fitting the mean number of licks emitted by the LEWs ($p = 26.3$), suggesting that changes in mean number of licks occurred faster in the former than in the latter strain. The ending point of the line fitting the mean number of licks emitted by the LEWs is higher ($A_2 = 7313$) than that (A_2

= 4044) of the line fitting the mean number of licks emitted by the SHRs, confirming that the LEWs emitted more licks during the blackout period than the SHRs.

The mean number of licks that the group of the SHRs (circles) and LEWs (squares) emitted before starting the cycles are plotted in Figure 9 against the delay components of the concurrent chain procedure. Note logarithmic base-2 scale on the y-axis. Except for blocks 1 and 2 showing that the number of licks increased across delay components, blocks 8 to 10 show either no changes or few changes in the mean number of licks that each strain emitted before starting the cycles. All graphs show that the SHRs emitted more licks before starting the cycles of the delay components than those emitted by the LEWs. The number of licks that the SHRs emitted in blocks 1 to 10, ranging from 50 to 1411 (Mdn = 735), were significantly greater ($U = 3209$, $p = .00$) than the number of licks emitted by the LEWs ranging from 2 to 469 (Mdn = 149). Table 3 shows the resulting parameters from fits of Eq. 3 to mean number of licks produced by the SHRs and LEWs before starting the cycles of the delay components. All blocks show that Eq. 3 fitted the data produced by the SHRs ($R^2 = .448$) and LEWs ($R^2 = .457$) well. Generally, the starting and ending points of the lines (A_1 and A_2 , respectively) fitting the data produced by the SHRs, have values greater across blocks of sessions than those corresponding to the data produced by the LEWs. The inflection points of the curves (x_0) fitting the data produced by the LEWs are smaller than those fitting the data produced by the SHRs, indicating that the LEWs number of licks moved to asymptotical level faster than the SHRs. However, the slopes of the curves fitting the data produced by the SHRs were steeper than the slopes of the lines fitting the data produced by the LEWs, suggesting faster changes in the number of licks before starting the cycles for the SHRs than for the LEWs. Some parameters show aberrant values due to poor fits of Eq. 3 caused by licks not varying across delay components.

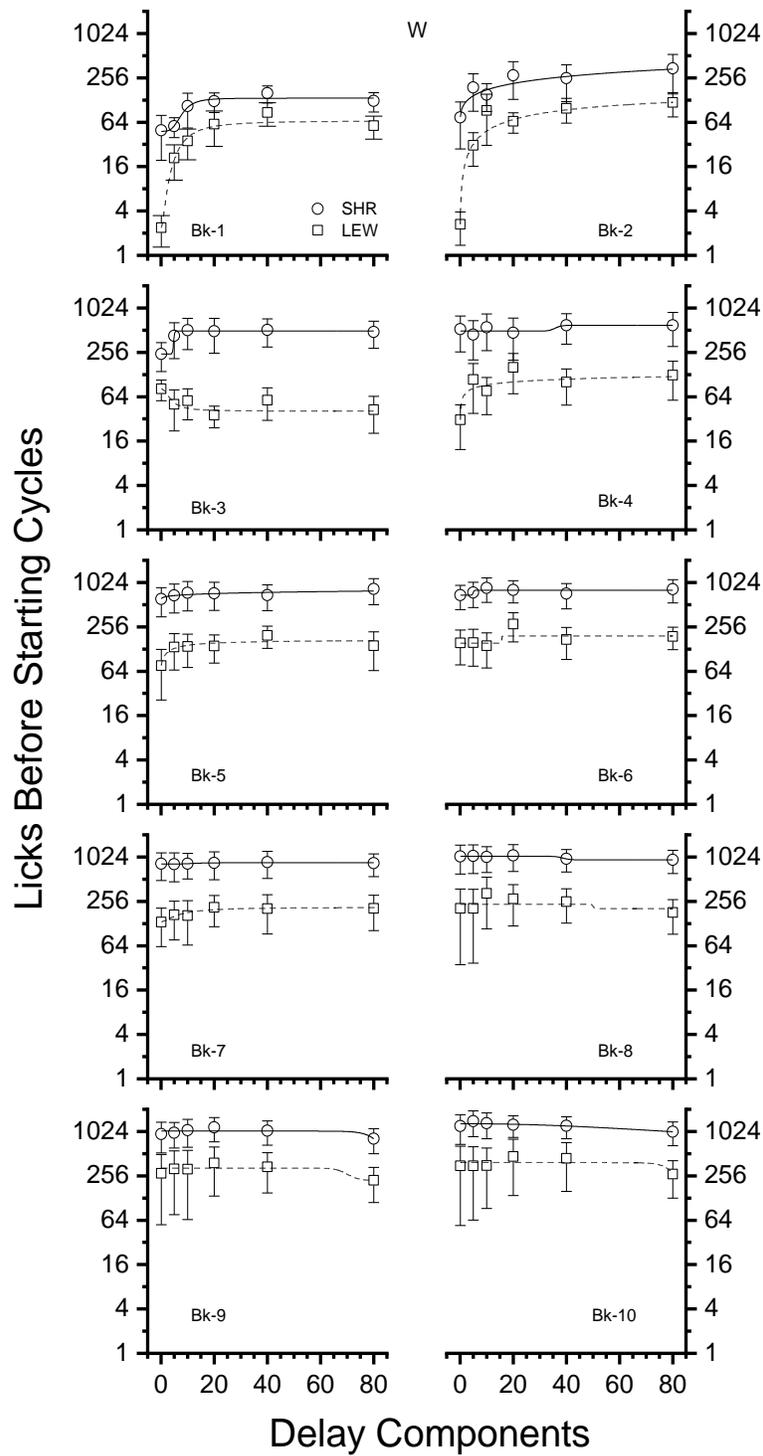


Figure 9. The number of licks before starting the cycles against delay components. Note logarithmic scale base-2 on the y-axis.

Table 3. Resulting parameters from fits of Eq.3 to water consumed (ml).

Block	SHR				
	A ₁	A ₂	x ₀	p	R ²
1	48	135.8	8.9	3.7	0.883
2	58	43862.6	1.5E+07	0.4	0.733
3	244	500.8	4.8	24.7	0.988
4	497	597.7	35.9	29.8	0.017
5	574	30022.7	4.2E+10	0.2	0.215
6	689	802.9	5.0	28.3	-0.177
7	824	854.6	12.5	5.6	0.153
8	1048	934.3	38.7	28.4	0.796
9	1036	-1174.1	88.6	21.6	0.265
10	1307	443.6	109.9	2.1	0.612
Mean	632	7698	4.E+09	14	0.448
	LEW				
	A ₁	A ₂	x ₀	p	R ²
1	2.4	66.9	8.5	1.9	0.918
2	0.6	198.6	46.4	0.7	0.951
3	82.0	40.8	3.3	2.1	0.312
4	-1623.8	1834.7	26.9	0.0	0.670
5	71.4	172.9	3.4	0.8	0.503
6	154.1	192.6	15.7	376.5	-0.367
7	135.0	212.5	8.0	1.5	0.775
8	234.7	204.0	50.0	206.7	0.000
9	325.9	220.7	69.7	31.5	0.533
10	387.0	-3038.3	92.4	23.2	0.277
Mean	-23.1	10.5	32.4	64.5	0.457

The mean number of licks that the SHRs (circles) and LEWs (squares) emitted during the initial link when the SS and LL levers were extended into the chamber, are plotted in Figure 10 as a function of the delay to deliver the LLR. From top to bottom the graphs are organized by blocks of sessions. Each pair of graphs shows licks emitted after pressing the SS lever (left) and after pressing the LL lever (right). The multiple graphs show that the SHRs emitted more licks in the

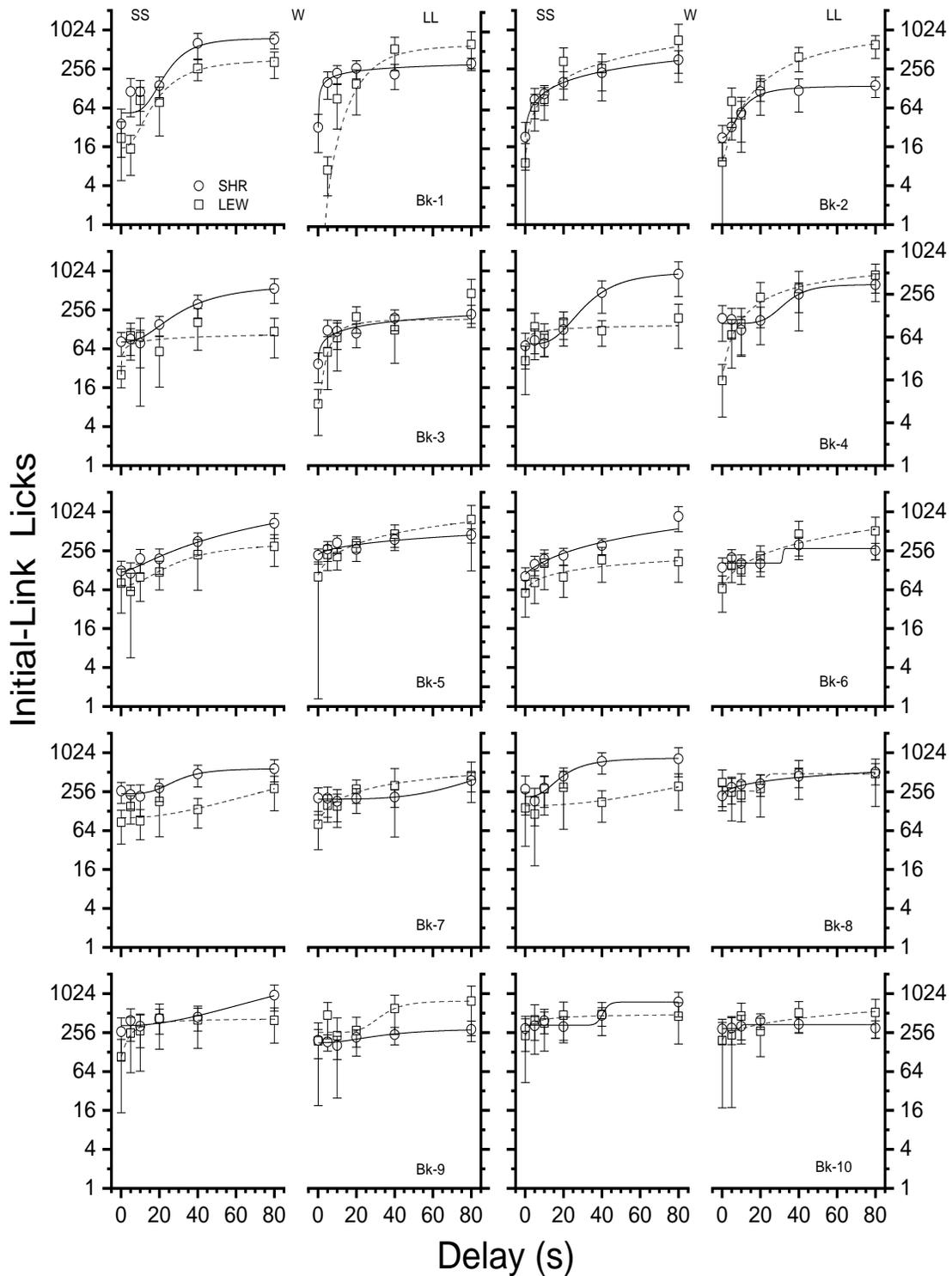


Figure 10. Number of licks during the initial link after pressing the SS and LL levers against the delay to the LLR. Note logarithmic scale base-2 on the y-axis.

initial link after pressing the SS lever than those emitted by the LEWs; the opposite result, however, is observed in the graphs showing that the LEWs emitted more licks in the initial link after pressing the LL lever than those emitted by the SHRs. Mann-Whitney U tests revealed that the number of licks emitted by the SHRs in the initial link after pressing the SS lever, ranging from 23 to 914 (Mdn = 246) was significantly greater ($U = 2366$, $p = .00$) than the number of licks emitted by the LEWs in the initial link after pressing the SS lever, ranging from 9 to 705 (Mdn = 157). Yet, the number of licks that the SHRs emitted in the initial link after pressing the LL lever, ranging from 22 to 510 (Mdn = 201) was not significantly different ($U = 1640$, $p = .40$) from the number of licks emitted by the LEWs in the initial link after pressing the LL lever ranging from 0 to 782 (Mdn = 228).

Eq. 3 fitting licks emitted by the SHRs after pressing the SS lever in the initial link, with R^2 ranging from .654 to .991 ($M = .837$), did a better job than fitting the licks emitted by the LEWs, with R^2 ranging from -.584 to .932 ($M = .512$). Table 4 shows the resulting parameters. The starting and ending points of the lines (A_1 and A_2 , respectively) fitting licks emitted by the SHRs after pressing the SS lever, have values greater than those corresponding to the line fitting licks emitted by the LEWs. The inflection points of the curves (x_0) fitting licks emitted by the LEWs are larger than those fitting licks emitted by the SHRs, suggesting that licks emitted by the SHRs moved to asymptotical level faster than those emitted by the LEWs. The slopes of the lines fitting licks emitted by the SHRs were steeper than the slopes of the lines fitting licks emitted by the LEWs, suggesting faster changes in licks emitted after pressing the SS lever in the SHRs than in the LEWs.

For the data produced by the SHRs, Eq. 3 accounted for more variability in the number of licks that occurred after pressing the LL lever, with R^2 ranging from -.766 to .974 ($M = .656$), than for the data produced by the LEWs, with R^2 ranging from .000 to .974 ($M = .552$).

Table 4. Resulting parameters from fits of Eq. 3 to licks emitted in the initial link.

Block	SS Lever					Block	LL Lever				
	SHR						SHR				
	A ₁	A ₂	x ₀	p	R ²		A ₁	A ₂	x ₀	p	R ²
1	53	766	31.6	4.1	0.699	1	-70	535	13.0	0.3	0.951
2	17	6.E+05	1.9E+07	0.6	0.991	2	22	140	1.4E+01	2.3	0.974
3	81	647	45.3	2.5	0.951	3	15	39956	1.3E+09	0.3	0.848
4	76	992	42.8	3.8	0.968	4	100	352	36.6	5.6	0.820
5	120	4875	331.1	1.4	0.848	5	111	1.E+06	5.3E+07	0.6	0.677
6	110	9.E+07	3.9E+07	0.9	0.698	6	165	277	31.7	1.E+02	0.533
7	238	584	31.9	3.9	0.920	7	196	29929	322.0	3.7	0.949
8	214	858	24.0	2.9	0.875	8	210	1.E+05	1.7E+07	0.5	0.945
9	327	1.E+07	7234.2	2.2	0.654	9	178	301	37.6	2.2	0.626
10	332	760	41.2	25.0	0.771	10	295	340	9.9	25.1	-0.766
Mean	157	1.E+07	5.8E+06	4.7	0.837	Mean	122	1.E+05	1.E+08	15.3	0.656
Block	LEW					Block	LEW				
	A ₁	A ₂	x ₀	p	R ²		A ₁	A ₂	x ₀	p	R ²
	A ₁	A ₂	x ₀	p	R ²		A ₁	A ₂	x ₀	p	R ²
1	15	366	31.6	2.6	0.733	1	0	654	31.6	3.0	0.000
2	7	4.E+07	2.9E+07	0.9	0.796	2	10	1123	69.8	1.6	0.814
3	-425	276	0.0	0.1	0.462	3	9	184	8.6	1.9	0.676
4	-855	215	0.0	0.2	0.675	4	15	795	58.4	1.1	0.974
5	74	348	39.3	2.2	0.859	5	43	2.E+07	2.0E+07	0.9	0.849
6	53	589	654.8	0.6	0.471	6	68	4.E+05	2.1E+05	0.9	0.725
7	101	2.E+06	6344.1	2.2	0.010	7	78	956	112.3	0.8	0.858
8	156	5.E+06	8074.0	2.3	-0.584	8	262	484	21.9	23.1	0.417
9	107	421	6.4	1.4	0.932	9	257	787	35.9	5.7	0.153
10	216	511	4.5	0.8	0.770	10	189	4.E+05	1.0E+07	0.6	0.050
Mean	-55	5.E+06	3.E+06	1.3	0.512	Mean	93	3.E+06	3.E+06	4.0	0.552

For the starting and ending points of the curve fitting the data produced by the SHRs, parameters A₁ and A₂ show values greater than those corresponding to the data produced by the LEWs. Except for some unusual values in estimates of x₀ caused by poor fits of Eq. 3, the parameter x₀ estimated higher values for the data produced by the SHRs than the data produced by the LEWs, indicating that the SHRs' licks after pressing the LL lever moved to an asymptotical level sooner than the

LEWs' licks. Congruently, the slopes of the lines fitting the data produced by the SHR were steeper than those of the lines fitting the data produced by the LEWs.

For the group of the SHRs (circles) and the group of the LEWs (squares), Figure 11 shows mean number of licks emitted in the terminal link during delays of 5, 10, 20, 40, and 80 s to the LLR. The lines are the best fits of Eq. 3 to mean number of licks. Each block of session shows that mean number of licks increased with increasing delay to deliver the LLR. Early in training (blocks 1 to 4) the LEWs emitted more licks during the delays to the LLR than the SHRs. The mean number of licks emitted by the LEWs in blocks 1 to 4 ranging from 0 to 348 (Mdn = 10), was not significantly different ($U = 193.5$, $p = .870$) from mean number of licks emitted by the SHRs ranging from 0 to 424 (Mdn = 12). Blocks 5 to 8 show lines of best fit close to one another, suggesting that both strains emitted a comparable mean number of licks during the delays to the LLR; confirming this result, the mean number of licks emitted by the LEWs ranging from 0 to 320 (Mdn = 17) was not significantly different ($U = 197$, $p = .945$) from mean number of licks emitted by the SHRs ranging from 0 to 186 (Mdn = 9). Blocks 9 and 10 show that mean number of licks emitted by the LEWs decreased, contrasting with mean number of licks emitted by the SHRs that did not change: the LEWs' mean number of licks ranging from 0 to 152 (Mdn = .3) was significantly smaller ($U = 78$, $p = .036$) than the SHRs' mean number of licks ranging from .8 to 290 (Mdn = 20). Table 5 summarizes resulting parameters from fits of Eq. 3 to mean number of licks emitted in the terminal link by the SHRs and LEWs. Estimates of the starting (A_1) and ending (A_2) points of the curves fitting the data produced by the SHRs across blocks of sessions ($M = 0$ and 190, respectively) are comparable to those estimated for the data produced by the LEWs ($M = 0$ and 223, respectively).

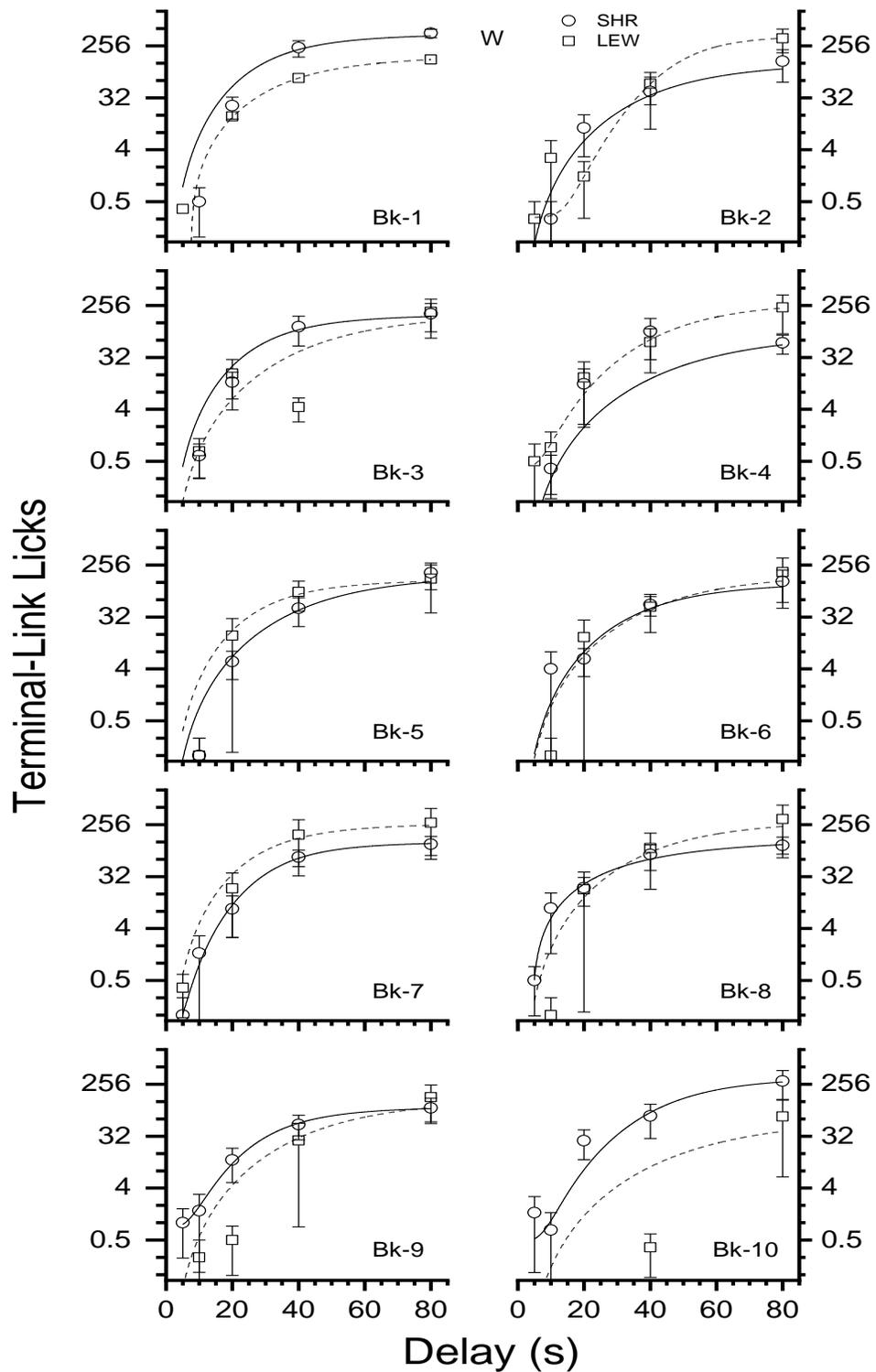


Figure 11 Mean terminal-link licks as a function of the delays to deliver LLR. From top to bottom the graphs are organized by blocks of sessions. Note logarithmic base-2 scale on the y-axis.

The inflection points of the curves (x_0) fitting the data produced by the SHRs ($M = 50$) are like the inflection points of the curves fitting the data produced by the LEWs ($M = 55$). Also, the slopes (p) of the lines fitting the data produced by the SHRs ($M = 3.1$) are like the slopes of the lines fitting the data produced by the LEWs ($M = 3.3$), showing similar rates of licks for both strains across blocks of sessions.

Table 5. Parameters from fits of Eq.3 to terminal-link licks.

Block	SHR				
	A_1	A_2	x_0	p	R^2
1	0.0	423.5	39.0	3.0	0.000
2	0.0	138.8	57.1	3.0	0.000
3	0.0	182.6	38.4	3.0	0.000
4	0.0	90.5	71.3	3.0	0.000
5	0.0	186.3	60.4	3.0	0.000
6	0.0	133.4	50.1	3.0	0.000
7	0.1	129.5	39.4	3.6	0.955
8	-1.7	161.6	49.2	1.9	0.902
9	0.8	106.0	39.8	3.3	0.958
10	0.5	350.2	55.0	3.7	0.020
Mean	0	190.2	50.0	3.1	0.284
Block	LEW				
	A_1	A_2	x_0	p	R^2
1	-1.1	181.7	46.9	2.8	0.999
2	0.3	382.8	54.1	5.9	0.673
3	0.0	198.5	63.2	3.0	0.000
4	0.4	307.8	58.3	3.5	0.729
5	0.0	147.3	38.0	3.0	0.000
6	0.0	192.3	60.0	3.0	0.000
7	0.0	275.9	38.0	3.0	0.000
8	0.0	319.6	56.1	3.0	0.000
9	0.0	152.0	63.9	3.0	0.000
10	0.0	70.6	74.7	3.0	0.000
Mean	0.0	222.8	55.3	3.3	0.240

Estimates of R^2 show that Eq. 3 fitting the data produced by the SHRs accounted for more

variability in mean number of licks late in training (blocks 7 to 9) than early in training (blocks 1 to 6). In contrast, estimates of R^2 show that Eq. 3 fitting the data produced by the LEWs accounted for more variability in mean number of licks early in training (blocks 1 and 2) than late in training (blocks 5 to 10).

Condition NW₂

In the redetermination to the no water condition (NW₂), the bottle of water was removed from the chamber leaving the metal spout available in the back wall for the rats to lick during the session. For the choices that the SHRs and the LEWs made in NW₂, Figure 12 shows mean proportions of LL choice as a function of delay to LLR (other details as in Figure 1).

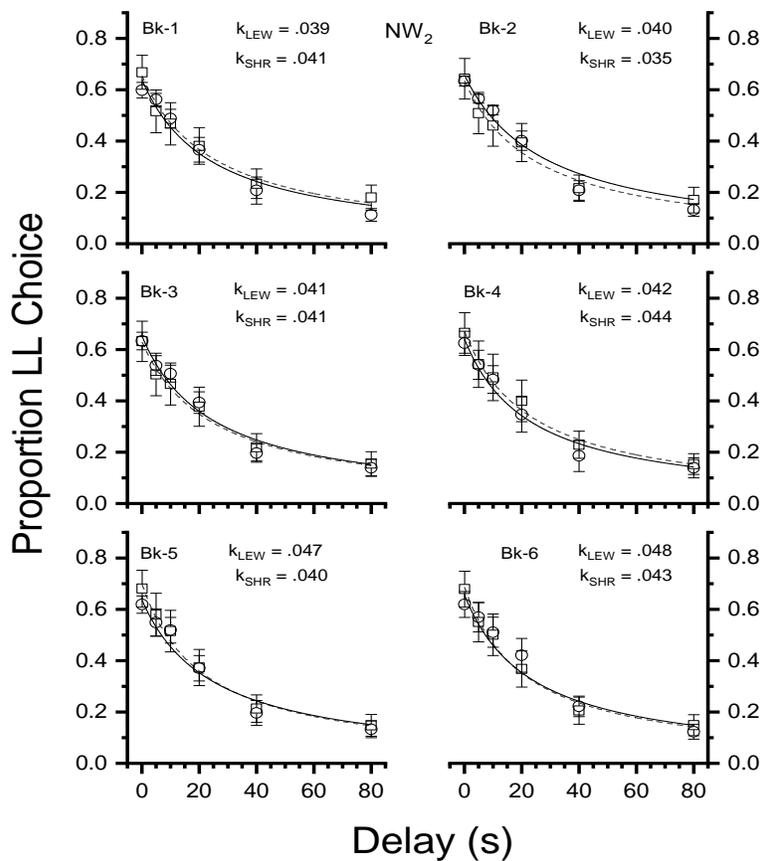


Figure 12. Proportion of LL choice computed in NW₂ as a function of the delay to LLR.

With lines of best fit overlapping across blocks of sessions, the graphs show that the discounting functions produced by the SHRs were like those produced by the LEWs. All discounting functions show that the proportion of LL decreased as a function of the increasing delay to the LLR. Table 6 shows resulting parameters from fits of Eq. 1 to the data produced by the SHRs and the LEWs. Eq. 1 fitted the data produced by the SHRs and the LEWs well, with R^2 ranging from .962 to .981 ($M = .967$) for the former and from .973 to .990 ($M = .985$) for the latter. Estimates of sensitivity of choice to the magnitude of the LLR (A) and discounting rate (k) show little changes across blocks of sessions. For the data produced by the SHRs estimates of A ranged from .641 to .659 ($M = .649$) and from .632 to .701 ($M = .665$) for the data produced by the LEWs. Discounting rates (k) estimated for the choices made by the SHRs ranged from .035 to .044 ($M = .041$) and from .039 to .048 ($M = .043$) for the choices made by the LEWs.

Table 6.
Hyperbolic-decay model, resulting parameters (NW_2).

Block	A		k		R^2	
	SHR	LEW	SHR	LEW	SHR	LEW
1	0.641	0.656	0.041	0.039	0.964	0.985
2	0.659	0.638	0.035	0.040	0.962	0.973
3	0.655	0.632	0.041	0.041	0.962	0.986
4	0.643	0.673	0.044	0.042	0.981	0.990
5	0.639	0.701	0.040	0.047	0.969	0.987
6	0.658	0.690	0.043	0.048	0.963	0.988
Mean	0.649	0.665	0.041	0.043	0.967	0.985

Estimates of discounting rate (k) and sensitivity of choice to the magnitude of the LLR (A) for the choices made by the individual SHRs and LEWs (unfilled symbols), are plotted in Figure 13 as a function of blocks of sessions.

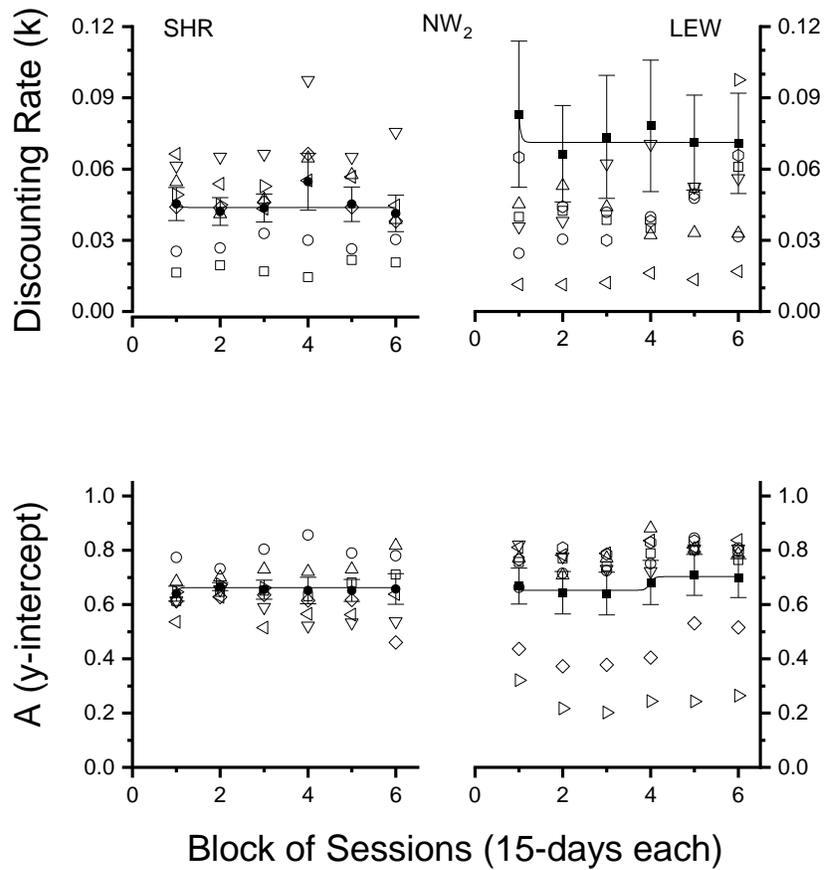


Figure 13. For the data of the individual SHRs and LEWs, k and A against block of sessions. Filled circles and squares represent mean values of k and A for the group of SHRs and the group of the LEWs, respectively. Lines are the best fits of Eq. 3.

The top graphs of Figure 13 show discounting rates produced by the individual LEWs that are slightly higher than the discounting rates produced by the individual SHRs. However, the discounting rates produced by the LEWs ranging from .01 to .24 (Mdn = .04) were not significantly different ($U = 735, p = .80$) from the discounting rates produced by the SHRs ranging from .01 to .09 (Mdn = .04). The bottom graphs show estimates of A for the choices made by the individual LEWs ranging from .20 to .88 (Mdn = .76), that are significantly smaller ($U = 489, p = .007$) than estimates of A for the choices made by the SHRs ranging from .40 to .85 (Mdn = .64).

Mean discounting rates produced by both strains varied little across blocks of sessions, resulting in poor fits of Eq. 3 for mean data produced by the group of the SHRs ($R^2 = -1.42$) and by the group of the LEWs ($R^2 = -.205$). Except for the A_1 parameter estimating aberrant values for the starting point of the flat lines fitting mean discounting rates produced by both strains, the ending point of the line fitting mean data produced by the LEWs shows a value ($A_2 = .07$) higher than that of the line fitting mean data produced by the SHRs ($A_2 = .04$). The inflection points of the fitting lines show that mean discounting rates produced by the SHRs moved to an asymptotical level earlier in training ($x_0 = .34$) than mean discounting rates produced by the LEWs ($x_0 = .68$). Yet, the slope of the line (p) fitting mean discounting rates produced by the LEWs ($p = 23.8$) is steeper than that of the line fitting mean discounting rates produced by the SHRs ($p = 19.1$).

Eq. 3 did a better fitting mean estimates of A for the data produced by the group of the LEWs ($R^2 = .614$) than fitting the mean data produced by the group of the SHRs ($R^2 = .250$). The starting ($A_1 = .65$) and ending points ($A_2 = .70$) of the line fitting mean estimates of A for the choices made by the group of the LEWs, show higher values than those of the line fitting mean estimates of A for the choices made by the group of the SHRs ($A_1 = .52$ and $A_2 = .66$, respectively). The inflection point of the curve fitting mean estimates of A for the choices made by the LEWs ($x_0 = .40$) is smaller than the inflection point of the curve fitting mean estimates of A for the choices made by the SHRs ($x_0 = .94$), suggesting that the LEWs' sensitivity to the LLR reached asymptotical level faster than the SHRs' sensitivity to the LLR. The slope of the line fitting mean estimates of A for the choices made by the group of the LEWs ($p = 78$) is steeper than that of the line fitting mean estimates of A for the choices made by the group of the SHRs ($p = 27$), indicating that the LEWs developed faster changes in sensitivity to the LLR than the SHRs.

The AUC computed with the choices made by the SHRs and LEWs in the NW₂ condition, are plotted in Figure 14 against blocks of sessions. The lines are the best fits of Eq 3 to mean data.

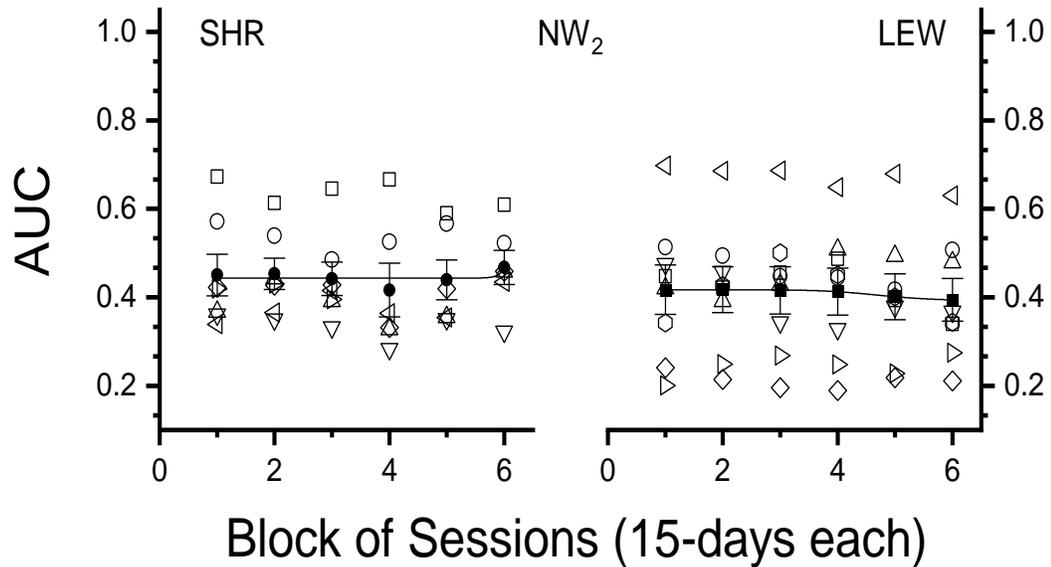


Figure 14. AUCs for the choices made by the SHRs and LEWs against blocks of sessions. Unfilled symbols stand for AUCs computed with choices made by the individuals. Filled circles (SHRs) and squares (LEWs) stand for AUC computed with choices made by the groups.

Generally, the graphs show that the AUCs computed with the choices made by the individual LEWs ($M = .41, SE = .05$), are smaller than the AUCs computed with the choices made by the individual SHRs ($M = .45, SE = .05$). Nonetheless, the AUCs computed with the choices made by the individual SHRs, ranging from .28 to .67 ($Mdn = .42$), were not significantly different ($U = 797, p = .719$) from the AUCs computed with the choices made by the individual LEWs, ranging from .19 to .70 ($Mdn = .44$).

For the choices made by the group of the SHRs mean AUCs show negligible changes across blocks of sessions resulting in a poor fit of Eq. 3 ($R^2 = -.239$). In contrast, for the choices made by the group of the LEWs mean AUCs decreased across blocks of sessions resulting in a

good fit of Eq. 3 ($R^2 = .995$). The inflection point of the line fitting mean AUCs computed for choices made by the group of LEWs ($x_0 = 4.75$), is smaller than the inflection point of the line fitting mean AUCs computed for the choices made by the SHRs ($x_0 = 7.78$), indicating that the AUCs produced by the LEWs moved to asymptotical level earlier in training than the AUCs produced by the SHRs. Due to minimal changes in AUCs shown by the SHRs across blocks of sessions, estimates of the parameters A_1 , A_2 , and p resulted in aberrant values. Contrasting with the line fitting mean AUCs computed with the choices made by the LEWs showing values of .42, .39, and 9.2 for the parameters A_1 , A_2 , and p , respectively.

The number of licks that the rats emitted to the spout of the bottle during the blackout periods are plotted in Figure 15 against blocks of sessions.

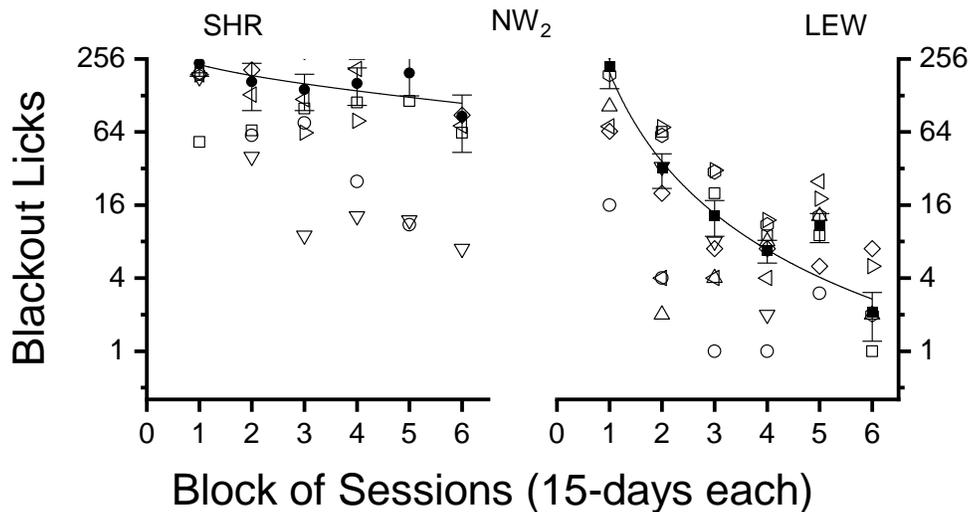


Figure 15. Licks emitted during blackout periods against blocks of sessions. Unfilled symbols stand for the licks emitted by the individuals and filled circles and squares for the mean licks emitted by the group of the SHRs and the group of the LEWs, respectively.

The graphs show that mean licks emitted to the spout of the bottle during the blackouts decreased with increasing blocks of sessions, mean licks emitted by the SHRs ranging from 86.3 to 236.1 (Mdn = 163.6) are significantly different ($U = 31$, $p = .045$) from mean licks emitted by the LEWs ranging from 2.1 to 224.1 (Mdn = 11.9). Eq. 3 fitting mean data produced by the LEWs did a better job ($R^2 = .556$) than fitting the mean data produced by the SHRs ($R^2 = .180$). The slope of the line fitting the mean number of licks emitted by the LEWs is steeper ($p = 2.45$) than the slope of the line fitting the mean number of licks emitted by the SHRs ($p = 0.19$), suggesting that licks emitted during the blackouts by the former decreased faster than licks emitted by the latter strain. The inflection point of the curve fitting mean licks emitted by the LEWs during blackouts ($x_0 = 0.56$), shows that licks moved to asymptotical level earlier in training, and the ending point of the curve ($A_2 = 2.45$) indicates that licks decreased notoriously at the end of the NW₂ condition. Estimates of the parameters A_1 , A_2 , x_0 for mean licks emitted by the SHRs resulted in unusual values due to small decreases in number of licks emitted across blocks of sessions (flat fitting line).

For the six blocks of sessions of the NW₂ condition, the number of licks that the SHRs and LEWs emitted before starting the cycles were averaged and plotted in Figure 16 against the delay components. The continuous and dotted lines are the best fitting lines generated by Eq. 3. The number of licks that the SHRs before starting the cycles, ranging from 5.2 to 19.6 (Mdn = 12.3) was significantly greater ($U = 36$, $p = .005$) than the LEWs, ranging from .3 to 1.8 (Mdn = 1.1). Eq. 3 fitted the data produced by the SHRs ($R^2 = .885$) and LEWs ($R^2 = .542$) well. The starting and ending points of the curve fitting the number of licks emitted by the SHRs ($A_1 = 6.1$ and $A_2 = 19.1$, respectively) show values that are greater than those corresponding to the number of licks emitted by the LEWs ($A_1 = 0.4$ and $A_2 = 1.4$, respectively),

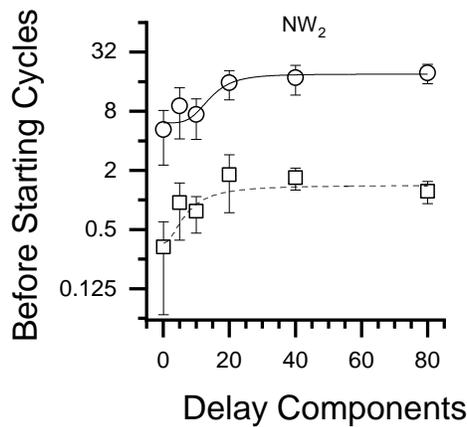


Figure 16. Licks emitted before starting cycles against delay components. Circles stand for data produced by the SHRs and squares for the data produced by the LEWs. Note logarithmic base-2 scale on the y-axis.

confirming that the SHRs emitted more licks before starting the cycles than the LEWs. For the line fitting the number of licks emitted by the SHRs, the inflection point of the line ($x_0 = 16.1$) shows a greater value than the inflection point of the line fitting the number of licks emitted by the LEWs ($x_0 = 9.7$), suggesting that the LEWs number of licks moved to asymptotical level sooner than those emitted by the SHRs. Congruently, the slope of the line fitting the number of licks emitted by the SHRs ($p = 4.1$) is steeper than the slope of the line fitting the number of licks emitted by the LEWs ($p = 2.0$), indicating that the number of licks emitted by the SHRs changed faster than those emitted by the LEWs.

Licks emitted in the initial link, after pressing the SS and LL levers, are plotted in Figure 17 as a function of the delay to deliver LLR. (Other details as in Figure 16). The left graph shows that the SHRs emitted more licks to the spout of the bottle after pressing the SS and LL levers than those emitted by the LEWs (right graph). A Mann-Whitney test revealed that the number of licks emitted by the SHRs after pressing the SS lever, ranging from 1.3 to 53 (Mdn = 5.5) is not

significantly different ($U = 30, p = .065$) from the number of licks emitted by the LEWs ranging from 0 to 3.9 (Mdn= 0.9). However, the number of licks that the SHRs emitted in the initial link after pressing the LL lever, ranging from 2.9 to 34.5 (Mdn = 11.7) is significantly greater ($U = 3, p = .020$) than the number of licks that the LEWs emitted after pressing the LL lever, ranging from 0 to 7.7 (Mdn = 0.5).

For the number of licks emitted in the initial link after pressing the SS lever, Eq. 3 fitting data produced by the SHRs ($R^2 = .994$) did a better job than fitting data produced by the LEWs ($R^2 = .000$). The starting point ($A_1 = 1.4$) and ending point ($A_2 = 104.8$) of the line fitting the number of licks emitted by the SHRs, show values higher those corresponding to the number of licks emitted by the LEWs ($A_1 = 0$ and $A_2 = 3.9$, respectively). The inflection point ($x_0 = 46.5$) of line fitting the data produced by the LEWs, indicates that the licks emitted by the LEWs reached asymptotical level earlier than the licks emitted by the SHRs ($x_0 = 80.0$). Also, the slope of the line fitting the data produced by the LEWs ($p = 3$) is steeper than the slope of the line fitting the data produced by the SHRs ($p = 2$), indicating that licks emitted by the LEWs changed faster than those emitted by the SHRs.

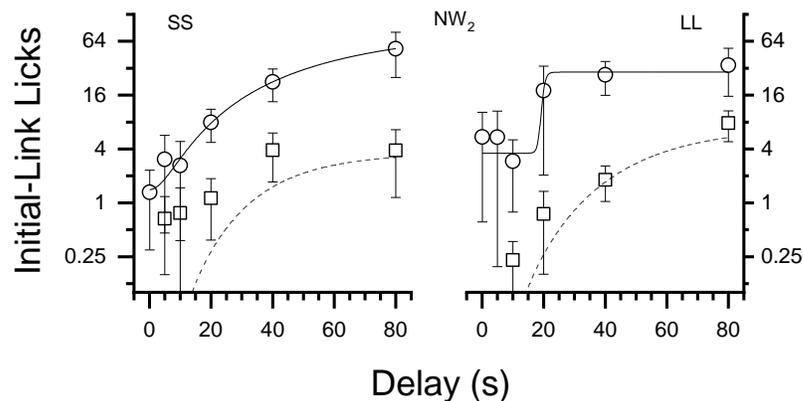


Figure 17. Licks emitted in the initial link after pressing the SS and LL levers against delays to deliver the LLR. Circles stand for data produced by the SHRs and squares for the LEWs

Similarly, Eq. 3 fitting the number of licks emitted by the SHRs after pressing the LL lever did a better job ($R^2 = .848$) than fitting the number of licks emitted by the LEWs ($R^2 = .000$). The values of the starting and ending points of the curve fitting the data produced by the SHRs ($A_1 = 3.6$ and $A_2 = 28.9$, respectively) are greater than the values of the starting and ending points of the curve fitting the data produced by the LEWs ($A_1 = 0$ and $A_2 = 7.8$, respectively). However, the inflection point ($x_0 = 19.8$) of line fitting the data produced by the SHRs, shows that the licks emitted by the SHRs reached asymptotical level earlier than the licks emitted by the LEWs ($x_0 = 61.0$). The licks emitted by the SHRs after pressing the LL lever changed faster ($p = 32.7$) than those emitted by the LEWs ($p = 3.0$).

The last analysis looked at the number of licks emitted in the terminal link during the delay to deliver the LLR with the lever extended into the chamber.

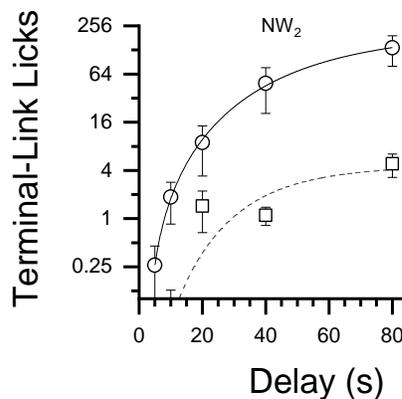


Figure 18. Licks emitted in the terminal link against delays to deliver LLR. For the six blocks of sessions in the NW_2 condition, computations of number of licks emitted in the terminal link were averaged and plotted in Figure 18 as a function of delays to deliver the LLR. (Other details as in Figure 16).

During delays to deliver the LLR, the SHRs emitted more licks to the spout of the bottle than the LEWs. However, the number of licks emitted by the SHRs in the terminal link ranging

from 0.3 to 136.0 (Mdn = 8.9) were not significantly different ($U = 21$, $p = .095$) from the number of licks emitted by the LEWs ranging from 0 to 4.9 (Mdn = 1.1). Eq. 3 fitted the data produced by the SHRs well ($R^2 = .987$), contrasting with the poor fit of Eq. 3 to the data produced by the LEWs ($R^2 = .000$) due to the small number of licks the LEWs made across delays. The starting points of the line fitting the data produced by the SHRs ($A_1 = -0.1$) shows a smaller value than the starting point of the line fitting the data produced by the LEWs ($A_1 = 0$), however, the ending point for the data produced by the SHRs ($A_2 = 247.8$) shows a value greater than that of the ending point of the line fitting the data produced by the LEWs ($A_2 = 4.9$). The inflection point of the line fitting the data produced by the SHRs ($x_0 = 73.3$) has a value greater than the value of the inflection of the data produced by the LEWs ($x_0 = 42.8$), suggesting that the number of licks emitted by the LEWs move to an asymptotical level earlier than the number of licks emitted by the SHRs. Lastly, the slope of the line fitting the licks emitted by the LEWs ($p = 3.0$) is steeper than the slope of the line fitting the licks emitted by the SHRs ($p = 2.5$), indicating that licks emitted by the LEWs changed faster than those emitted by the SHRs.

Discussion

NW₁ Condition

The present study extended the generality of findings showing that the performance of the SHR rat on a concurrent-chains procedure that varied the delay to the LLR within sessions, is comparable to that of the LEW rat (Hensley, 2021). For both strains the proportion of LL choice decreased with increasing delay to deliver the LLR (Fig. 1), and both strains learned to choose impulsively with extended training in the choice situation (Aparicio et. al., 2015, 2019, 2020). The results of the NW₁ condition showed that both strains produced low discounting rates early in training (blocks 1-4), but the LEWs produced higher discounting rates than the SHRs. In the middle of training (block 5), the LEWs and the SHRs produced similar discounting rates. For both

strains, however, discounting rates increased with increasing number of block of sessions (blocks 6-8). At the end of the training (blocks 9-10), the SHRs produced steeper discounting rates than the LEWs. These results are consistent with the theory that choosing impulsively in non-human animals is adaptive to the organism (Fawcett, McNamara & Houston, 2012).

Consistent with earlier research showing that Mazurs' (1987) hyperbolic decay model nicely fits discounting data produced by humans (e.g., Meyerson & Green, 1995; Rachlin et al, 1991) and non-human animals (e.g., Farrar et al., 2003; Green et al, 2007; Mazur, 2012; Stein et al, 2021), the present study showed that Eq.1 fits the discounting functions produced by the SHRs and LEWs well. Estimates of discounting rate (k in Eq. 1) for the discounting functions produced by the SHRs and LEWs increased with increasing number of blocks of sessions, confirming that both strains learned to choose to impulsively as a function of training (Fig. 2). Eq. 3 estimated that the SHRs' discounting rates moved to asymptotical level earlier in training (x_0), as well as increased faster (p) across blocks of sessions than the LEWs' discounting rates. A remarkable result was that values of the parameter A also increased as a function of the increasing number of blocks of sessions, indicating that sensitivity of choice to the magnitude of the LLR increased with the SHRs developing more sensitivity to the magnitude of the LLR than the LEWs.

The computation of the area under the discounting curve (Meyerson et al, 2001), a free theory estimate of delay discounting, confirmed the results of NW_1 condition. Early in training the choices of the LEWs produced smaller AUCs than the choices of the SHRs, indicating more impulsive choices in the former than in the latter. Both strains learned to choose impulsively with increasing number of block of sessions. Late in training, however, the AUCs produced by the LEWs were like those produced by the SHRs, suggesting similar levels of impulsive choice. For the choices made by the SHRs, Eq. 3 estimated a starting point (A_1) of the AUC higher than that

corresponding to the choices made by the LEWs, indicating that the LEWs made more impulsive choices at the beginning of training than the SHRs. Congruently, the ending point (A_2) of the AUC produced by the SHRs (Fig. 3) was like that produced by the LEWs, suggesting that both strains showed similar levels of impulsive choice at the end of training. The AUCs produced by the choices made by the LEWs, however, decreased faster (p) than the AUCs produced by the choices made by the SHRs, suggesting that the LEWs learned to choose more impulsively sooner than the SHRs.

W Condition

Condition W added a bottle of water to the choice situation to: (1) test the assumption that allowing the rats to drink during the delay to the LLR will reduce their impulsive choices, (2) assess the idea that polydipsia and impulsive choice are related; that is, rats developing polydipsia will also develop impulsive choice (Ibias & Pellon, 2011), and (3) confirm that polydipsia is induced by food acting as a phylogenetically important event [(PIE), Baum, 2021].

The results showed that the shape of the discounting functions produced by the SHRs in the W condition were like those they produced in the NW_1 condition. In contrast, the discounting function produced by the LEWs showed steeper slopes than the slopes of the discounting function that they produced in the NW_1 condition. This finding clearly shows that adding the bottle of water to the choice situation did not reduce impulsive choice in the SHRs and LEWs. Instead, the discounting functions produced by the SHRs with water available in the choice situation, were like those they produced in the NW_1 condition. The LEWs, however, made more impulsive choices across blocks of sessions than those they made without the water available in the choice situation. The parameters k and A (Eq. 1) confirmed these results. The discounting rates (k) produced by the SHRs were similar across blocks of sessions of the W condition, contrasting with the discounting

rates produced by the LEWs that were higher at the end of the W condition than at the beginning. Sensitivity to the magnitude of the LLR, however, showed the opposite result. A side by side comparison between Figures 2 and 5 revealed that the SHRs' sensitivity to the LLR (A) was enhanced with the water available in the choice situation. In contrast, the LEWs' sensitivity to the LLR was like that in the NW_1 condition. More evidence supporting these results came from Eq. 3 fitting estimates of k and A , doing a better job fitting estimates of k and A for the choices made by the LEWs than for the choices made by the SHRs. The starting and ending points of the lines fitting discounting rates produced by the LEWs are greater than those fitting discounting rates produced by the SHRs, confirming that the LEWs chose more impulsively than the SHRs. Also, the starting and ending points of the lines fitting estimates of A for the discounting functions produced by the LEWs were lower than estimates of A for those produced by the SHRs, confirming that the SHRs developed a higher sensitivity to the magnitude of the LLR than the LEWs.

Computations of AUC confirmed that while impulsive choice in the SHRs did not change with the water available in the choice situation, it increased in the LEWs. For the choices made by the SHRs in the W condition, computations of AUC showed values like those estimated in the NW_1 condition. The AUCs estimated for the LEWs in the W condition, however, were smaller than those corresponding to the NW_1 condition suggesting more impulsivity in the W condition. The findings showing that the LEWs produced steep discounting functions and small AUCs, are consistent with studies claiming that rats developing polydipsia will choose impulsively (Ibias & Pellón, 2011). Yet, the current results showing that the SHRs produced similar discounting rates and AUCs in the NW_1 and W conditions, do not support that claim and question the link between polydipsia and impulsive choice (Ibias & Pellón, 2014).

The present study measured the volume of water (ml) that the rats drank during the session, analyzing the number of licks emitted to the spout of the bottle during the blackouts, before starting the cycles, and in the initial and terminal links of the current-chains procedure. The results clearly showed that both strains drank water excessively during the session (Fig. 7). The SHR_s, however, drank substantially more water (about 14 ml) across sessions than the LEW_s (about 10 ml), suggesting that drinking water excessively in the SHR_s could be attributed to motor impulsivity (Winstanley et al., 2006) characterizing the SHR_s. Overall, the finding that both strains developed polydipsia during the session are consistent with the idea the drinking water was induced by food as a PIE (Baum, 2021).

The highest number of licks to the spout of the bottle occurred during the 1-min blackout periods (Fig. 8), with the LEW_s (about 8200) emitting more licks than the SHR_s (about 4100). This result is important because the blackouts were 1-min periods during which food was not available, capturing the main aspects of schedules inducing polydipsia during intervals between food deliveries (Falk, 1961). Although the highest number of licks were emitted in the blackout periods, the rats emitted a substantial number of licks before starting the cycles of the concurrent chains procedure, with the SHR_s emitting more licks across blocks of sessions than the LEW_s (Fig. 9). In the first blocks of sessions both strains emitted an increased number of licks across delay components, with the LEW_s' licks reaching asymptotical level sooner than the SHR_s' licks. Yet, both strains showed little changes in the number of licks across delay components for the last blocks of sessions. Because licking was interrupted by turning on the house light at the end of the blackout to signal the availability of the next cycles, the licks emitted before starting the cycles were most likely due to a run over effect of licking in one period to the next period. Since licks emitted in the blackout periods and before starting the cycles did not compete with pressing the

levers to produce food, both strains emitted the highest number of licks in these periods. These findings are consistent with the laws of allocation, induction, and covariance (Baum, 2018a, 2018b); showing that the SHRs and LEWs allocated behaviors of licking and pressing in the choice situation, these behaviors were induced by food as a PIE, and they did not compete with one another in the blackout periods and before starting the cycles.

However, licking during the initial and terminal links competed with pressing the levers to produce food causing a decrease in total licks with respect to blackouts and periods before starting the cycles. Figure 10 showed that the SHRs emitted more licks in the initial link after pressing the SS lever than the LEWs, but the LEWs emitted more licks in the initial link after pressing the LL lever. Although the former result suggests that licking might be due to hyperactivity characterizing the SHRs (Knardahl & Sagvolden, 1979; Sagvolden et. al., 1992), the latter result seems to indicate that the LEWs established a more efficient discrimination between the SS and LL levers, leading them to emit more licks after pressing the lever producing the LLR than the SHRs; perhaps due to poor sustained attention (Diana, 2002) and learning deficits (Meneses & Hong, 1998) in the SHR. A comparison between total licks emitted in the initial link (Fig. 10) and those emitted in the terminal link (Fig. 11) revealed a further decrease in overall licks across blocks of session, with the SHRs emitting more licks (about 250) than the LEWs (about 64). For both strains, however, licks emitted in the terminal link increased with increasing delay to the LLR due to the rats having more time to lick during longer delays to the LLR. Because pressing the lever competed with licking the spout of the bottle, overall licks decreased in the terminal link across blocks of sessions, more for the LEWs than for the SHRs due to hyperactivity in the latter strain. Together, these findings support the law of covariance by showing that food delivered by the LL lever induced the

activity on which it depends (pressing), producing a feedback loop between pressing that lever and the LLR (Baum, 2021).

Re-determination to NW₂ Condition

The re-determination to the no water condition (NW₂) assessed the possibility that the LEWs and SHRs, choosing between the SSR and LLR without the water available in the choice situation, will develop levels of impulsive choice like those they showed in the baseline (NW₁) condition. For this purpose, the bottle of water was removed from the chamber leaving the spout of the bottle available to record licks. The slopes of the discounting functions (Fig. 12) that the SHRs produced in 6-blocks of the NW₂ condition (mean $k = .041$), were like those they produced in both the last two blocks of the NW₁ condition (mean $k = .042$) and the 10-blocks of the W condition (mean $k = .041$). The discounting functions produced by the LEWs in the NW₂ condition, however, showed slopes (mean $k = .043$) steeper than the slopes (mean $k = .032$) of the discounting functions that they produced in the last two blocks of the NW₁ condition, and also steeper than the slopes (mean $k = .036$) of the discounting functions produced in the W condition. These findings suggest that whereas impulsive choice increased in the LEWs who kept learning to choose impulsively in the NW₂ condition, impulsive choice in the SHRs reached asymptotical levels in the initial NW₁ condition showing no further changes in discounting rates in the W and NW₂ conditions. These results were confirmed with the discounting rates (k) produced by the individual LEWs showing values slightly higher than the discounting rates produced by the individual SHRs (Figure 13). Although the ending point (A_2) of the line fitting the discounting rates produced by the LEWs was higher than the ending point for the discounting rates produced by the SHRs, and the slope of the fitting line for the former was steeper than that for the latter, there were no significant differences in discounting rates between the SHRs and the LEWs.

Sensitivity of choice to the magnitude of the LLR (A) in the re-determination to the NW₂ condition showed mixed results. While values of A for the discounting functions produced by the SHRs increased from the NW₁ condition (mean $A = .53$) to the W condition (mean $A = .68$), there were small changes in values of A from the W condition to the NW₂ condition (mean $A = .65$). However, the sensitivity to the magnitude of the LLR that the LEWs developed in the NW₁ condition (mean $A = .51$), increased in both the W condition (mean $A = .60$) and re-determination to the NW₂ condition (mean $A = .67$). These results suggest that in non-human animals sensitivity of choice to the magnitude of the LLR increase as a function of training, and they are consistent with those obtained in studies showing that when the parameter A is not assumed to be 1.0 LL choice at the y-intercept, A varies freely showing systematic changes across blocks of sessions (Aparicio et.al., 2019).

The areas under the discounting curve (AUCs) produced by the choices that the SHRs and LEWs (Fig. 14) made in the re-determination to the NW₂ condition ($M = .44$ and $.41$, respectively), were smaller than both AUCs produced in the W condition ($M = .46$ and $.43$, respectively), as well as AUCs produced in the initial NW₁ condition ($M = .49$ and $.46$, respectively). These findings confirmed that impulsive choice in non-human animals increases as a function of extended training in the impulsive task (Aparicio et. al., 2019).

Lastly, if water was important to maintain the behavior of licking, then the absence of water might cause the extinction of licking. But if licking occurred in the absence of water, then licking was induced by food and water was not necessary to maintain licking. Removing the water from the choice situation but leaving the spout of the bottle to record licks during the re-determination to the NW₂ condition, was important to demonstrate that licking was induced by food acting as a PIE (Baum, 2021), and it happened regardless of whether or not the behavior of licking produced

water in the choice situation. During the blackout periods the SHRs and LEWs licked the spout of the bottle, with the SHRs emitting more licks than the LEWs across blocks of the NW₂ condition (Fig. 15). Although for both strains licks showed a tendency to decrease in the last blocks of sessions, licks did not show complete extinction during the blackouts. Similarly, the SHRs and the LEWs continued to lick the spout of the bottle before starting cycles arranged by delay components, again with the SHRs emitting more licks to the spout than the LEWs. Licks in the initial link of the concurrent chain procedure persisted for both strains, with the SHRs emitting more licks after pressing the SS and LL levers than the LEWs. Finally, the SHRs' licks in the terminal link increased with increasing delays to the LLR, however, the LEWs' licks did not change systematically across delays showing a very low number of emissions. Together these findings are consistent with the laws of induction and covariance, showing that licking was induced by food and the behavior of pressing the levers to produce food competed with the behavior of licking the spout of the bottle (Baum, 2021).

Conclusions

The present study analyzed delay discounting and polydipsia in two animal models of ADHD, the SHRs and LEWs rats, responding to a concurrent chains procedure varying the delay to the LLR within sessions. This study extends the generality of earlier findings showing that impulsive choice in the SHRs is comparable to impulsive choice in the LEWs (Hensley, 2021): both strains produced discounting functions showing proportions of LL that decreased with increasing delay to the LLR, and both strains learned to choose impulsively with extended training in the choice situation. This result was confirmed with estimates of discounting rate (k in Eq. 1) produced by the SHRs and LEWs that increased with increasing number of blocks of sessions. Although early in training (NW₁) the LEWs discounted the LLR steeper (k was higher) than the

SHRs, late in training (W and NW₂) both strains produced similar discounting functions with comparable slopes and lines of best fit overlapping across blocks. Sensitivity of choice to the magnitude of the LLR (A) also increased as a function of extended training. This finding is important because when the parameter A is free to vary (i.e., it is not assumed to be 1.0 LL choice at y-intercept), it shows systematic changes across blocks of sessions (Aparicio et. al., 2019).

Adding the bottle of water in the choice situation did not affect the impulsive choices that the SHRs and LEWs made in the W condition, ruling out the possibility that adding an activity for the rats to engage in during the delay to the LLR (i.e., drinking water) will reduce their impulsivity. Results of the W condition showed that polydipsia was induced by food acting as a PIE (Baum, 2021). Most of the licking happened during the blackouts and periods before starting the cycle of the concurrent chains procedure, capturing the main aspects of schedules inducing polydipsia during intervals between food deliveries (Falk, 1961). Although licking was observed in the initial and terminal links of the concurrent chains procedure, in both links licking showed an overall tendency to decrease with respect to licking in the blackouts and periods before starting the cycles. Overall these results support the laws of allocation, induction, and covariance (Baum, 2018a, 2018b) showing that the SHRs and LEWs allocated the behaviors of licking and pressing, both behaviors were induced by food, and pressing the levers competed with licking the spout of the bottle because of the dependency between pressing and food (lever pressing increased and licking decreased across blocks of sessions). The analysis of consumption of water revealed the SHRs drank substantially more water and licked more in all components of the concurrent-chains procedure than the LEWs, perhaps due to motor impulsivity in the SHRs (Winstanley et al., 2006). In the NW₂ condition, both strains continued to lick the spout of the bottle in the absence of water in all components of the concurrent-chains procedure, showing that water was not necessary to

maintain the behavior of licking; instead, the behavior of licking was induced by food, supporting the law of induction (Baum, 2018a, 2018b).

Further research is needed to explore further the relation between delay discounting and polydipsia to identify the factors effecting impulsivity in non-human animals. At the present time it is possible to conclude that rats developing polydipsia will not necessarily discount the LLR more steeply than rats not developing polydipsia before learning the impulsive task.

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