

## Polydipsia and Impulsive Choice in Rodent Models of Attention-Deficit/Hyperactivity Disorder

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### Abstract

Impulsive choice and polydipsia were analyzed in Spontaneously Hypertensive (SHR) and Lewis (LEW) rats, two rodent models of Attention Deficit/Hyperactivity Disorder (ADHD). Impulsive choice was assessed in the initial link of a concurrent-chains procedure with presses on two levers. Two non-independent random interval schedules arranged entries to two terminal links, one delivering 1-food pellet with a 0.1-s delay and the other 4-food pellet with delays of 0.1, 5, 10, 20, 40, and 80 seconds presented in random order during the session. An ABA design allowed the rats to drink water (B), or not to drink water (A) during the session. The SHR and LEW made impulsive choices producing discounting functions indicating sensitivity of choice to magnitude of food and discounting rate increasing with increasing sessions of training. With the water available to drink both strains developed polydipsia, but it did not affect impulsive choice. The LEW produced discounting rates like those produced by the SHR. Drinking water occurred in blackouts and before starting the initial link, but it decreased in the initial and terminal links. Licking the spout of the bottle persisted when the water was removed from the choice situation. The laws of allocation, induction, and covariance describe the present findings.

**Keywords:** ADHD, SHR, LEW, impulsive choice, polydipsia.

### Resumen

Se analizó la elección impulsiva y la polidipsia en ratas espontáneamente hipertensas (SHR) y Lewis, dos roedores modelos del trastorno por déficit de atención e hiperactividad (ADHD). La elección impulsiva se evaluó con presiones en dos palancas disponibles en el eslabón inicial de un procedimiento concurrente encadenado. Dos programas de intervalo aleatorio funcionaron de manera dependiente organizando la entrada a dos eslabones terminales, uno para dar 1-pella de comida con una demora de 0.1 segundo y el otro para dar 4-pellas de comida con una demora de 0.1, 5, 10, 20, 40, o 80 segundos seleccionada y presentada en orden aleatorio en cada sesión. Un diseño *ABA* permitió a las ratas beber agua (B), o no beber agua (A) durante la sesión. Las ratas SHR y LEW eligieron impulsivamente produciendo funciones de descuento temporal mostrando incrementos en la tasa de descuento y una mayor sensibilidad a la magnitud de la comida con los incrementos en las sesiones de entrenamiento. Con el agua disponible para beber las dos cepas desarrollaron polidipsia sin que esto afectara sus elecciones impulsivas. La LEW produjo tasas de descuento similares a las producidas por la SHR. El mayor consumo de agua ocurrió en los periodos de oscuridad y antes de entrar al eslabón inicial, pero la polidipsia decreció en los eslabones inicial y terminal. Los lengüetazos a la pipeta de la botella persistieron con la botella vacía de agua en la situación de elección. Las leyes de distribución, inducción, y covariación describen los presentes hallazgos.

**Palabras clave:** ADHD, SHR, LEW, elección impulsiva, polidipsia.

<sup>1</sup> La referencia del artículo en la Web es: [https://www.conductual.com/articulos/Polydipsia\\_and\\_impulsive\\_choice\\_in\\_rodent\\_models\\_of\\_attention-deficit\\_hyperactivity\\_disorder.pdf](https://www.conductual.com/articulos/Polydipsia_and_impulsive_choice_in_rodent_models_of_attention-deficit_hyperactivity_disorder.pdf)

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### Polydipsia and Impulsive Choice in Rodent Models of Attention-Deficit/Hyperactivity Disorder

In the study of patterns of behavior labelled “impulsive” impulsivity is defined as a predisposition to rapid unplanned reactions to either internal or external stimuli (Bakhshani, 2014). Impulsivity is linked to short attention span, deficiencies in the inhibitory control of responses, hypersensitivity to delayed consequences, and hasty decision-making (Evenden, 1999). To study impulsivity, researchers distinguish between impulsive action and impulsive choice. Impulsive action is an excess of overall activity (Winstanley, Eagle, & Robbins, 2006), and impulsive choice is a hasty decision-making (Brunner & Hen, 1997) in situations arranging a choice between a smaller-sooner reinforcer (SSR) and a larger-later reinforcer (LLR). Choosing the SSR over the LLR indicates impulsive choice (Ainslie, 1974) and choosing the LLR more often than the SSR self-controlled choice (Logue, 1988). The preference for the LLR switches to the SSR with an increasing delay to the LLR, indicating that the value of the LLR (its efficiency at the time of choice) is discounted according to a behavioral process termed delay discounting (Myerson & Green, 1995) and described suitably by the hyperbolic-decay model (Mazur, 1987).

$$V = \frac{A}{1+kD}. \quad (1)$$

Where V stands for the current value of the LLR, A is the amount of the LLR, D is the delay to obtain the LLR, and K is a free parameter estimating how fast the LLR's value decays with increasing D. The greater the value of k, the higher the rate discounting the LLR indicating impulsive choice. The efficacy of the hyperbolic-decay model in describing delay discounting data produced by non-human animals is well documented (e.g., Aparicio, Hughes, & Pitts, 2013; Aparicio, Elcoro, & Alonso-Álvarez, 2015; Aparicio et al., 2019; 2020a; 2020b; Farrar et al., 2003; Mazur, 2012; Green et al., 2007; Stein et al., 2012).

The rationale behind studying the impulsive choices of Spontaneously Hypertensive (SHR) and Lewis (LEW) rats is that both are inbred strains of rats showing behaviors characterizing attention-deficit hyperactivity disorder (ADHD) such as inattention, impulsivity, learning difficulties, and hyperactivity affecting human children and adults (Farrar et al., 2003; Fox, Hand, & Reilly, 2008). Rats SHR and LEW develop irregular activity of dopamine (DA) and serotonin (5-HT) in diverse areas of the brain, supporting the idea that ADHD is a developmental disorder (Russell, 2007) and theoretical interpretations of it (Sagvolden, 2000). The dopamine transfer deficiency (DTD) hypothesis (Tripp & Wickens, 2024) proposes that a deficit in the transference of DA from a reinforcer to a stimulus preceding it, prevents the organism to connect that stimulus with the reinforcer increasing its sensitivity to the delay of reinforcement (Tripp & Wickens, 2008; 2009). Yet, a suitable activity of norepinephrine and 5-HT neurotransmitters is also required for organisms to tolerate the delay to reinforcement (Cardinal et al., 2004). SHR and LEW share the traits of inattention and hyperactivity endorsing three subtypes of ADHD: primarily inattentive (ADHD-IA), hyperactive-impulsive (ADHD-HI), and a combined subtype ADHD-C (Garcia & Kirkpatrick, 2013).

The SHR is a genetic model originally reproduced for hypertension, and the Wistar Kyoto (WKY) is the normotensive control of the SHR (Okamoto, 1969; Okamoto & Aoki, 1963). The Wistar (WIS) is the source strain of both the WKY and LEW, and the Fischer 344 (F344) is the inbred control of the LEW. The SHR is a validated model of ADHD (Sagvolden, 2000; Sagvolden, 2011), and the LEW is the alternative rodent-model of ADHD to the SHR (Aparicio, 2023; Garcia & Kirkpatrick, 2013). The SHR experiences irregular activity of DA in the striatum and mesolimbic systems (Nakamura et al., 2001; Oades, et al., 2005), it endures fast uptake of DA in the ventral striatum and nucleus accumbens causing impulsivity and tolerates low release of DA in the dorsal striatum interrupting its motor activity (Miller et al., 2012). The SHR has inadequacies of norepinephrine and 5-HT like those found in people diagnosed with ADHD (Toot et al., 2004). The LEW experiences irregular activity of DA and 5-HT in diverse areas of the brain (Burnet et al., 1966). The LEW has fewer D2 receptors in the striatum and core of nucleus accumbens, lesser D3 receptors

in the shell of nucleus accumbens and the olfactory tubercule, and fewer 5-HT binding sites in the hippocampus and frontal cortex than its inbred control the F344 (Flores et al., 1998; Selim and Bradberry, 1966).

Studies comparing impulsive choices made by LEWs with impulsive choices made by SHRs, indicate that LEWs made more impulsive choices early in training than SHRs (Aparicio, Hensley, & Malonson, 2022). But SHRs with prolonged experience in the choice situation made more impulsive choices than LEWs, indicating that impulsive choice in SHRs increases with their experience in the choice situation (Aparicio et al., 2019). Another important finding is that both strains have individuals producing steep discounting functions and individuals producing flat discounting functions, allowing researchers to make comparisons between high discounting rates and low discounting rates produced by individuals of each strain supporting the idea that LEWs are an appropriate control to SHRs (Aparicio et al., 2022). The present study explores this idea looking for a connection between polydipsia and impulsivity examined in previous studies (Aparicio, 2023; Íbias and Pellón, 2011; 2014).

Polydipsia is the behavior of drinking an excessive amount of water during the interval between consecutive food deliveries (Falk, 1961). Because polydipsia occurs in fixed time (FT) response-independent and fixed interval (FI) response-dependent schedules of reinforcement (Falk, 1966, 1969), polydipsia is known as schedule-induced polydipsia (SIP), or adjunctive behavior (Falk, 1971) to include activities like eating nonfood material, wheel running, and aggression also induced by intermittent schedules of reinforcement (Falk, 1970). Adjunctive behaviors take time to develop (Reynierse & Spainer, 1968), occur during timeouts (Wüttke, 1970), and following a brief presentation of a stimulus in second-order interval schedules of reinforcement (Rosenblith, 1970). It has been shown that adjunctive behaviors occur following each response on a differential reinforcement of low rates schedule, late in the interval of a long FT schedule (Segal, Oden, & Deadwyler, 1965), and when the last reinforcer of a FI schedule is delivered at the end of the session (Keehn & Colotla, 1970). Interim activities are adjunctive behaviors occurring when the probability of reinforcement is low and terminal behaviors are hardly observed (Staddon & Simmelhag, 1971). Induction is the process explaining occurrences of interim activities and their effects on operant activities (Segal, 1972). It replaces the notions of reinforcement and strength (Baum, 2012), where the role of a reinforcer is to induce the operant activities that it maintains (Baum, 2021). Induction is an important concept for a multiscale view of choice (Baum, 2018b) to analyze activities according to the laws of allocation, induction, and covariance (Baum, 2018a). The law of allocation claims that activities compete with one another for time which is important to understand behavior allocation (Baum, 2018a; 2018b). The law of induction maintains that phylogenetically important events (PIEs) allow the organism to survive and reproduce (Baum, 2021). The law of covariance analyzes the organism's sensitivity to events that vary together in the environment to determine which activities are induced by PIEs, causing induced activities to increase and non-induced activities to fade (Baum, 2021). Hence, activities induced and maintained by PIEs are operant activities that covary with PIEs, stimuli that covary with PIEs become "proxies" of the PIEs, and proxies induce activities like those induced by PIEs (Baum, 2021). For instance, food delivered contingent upon lever-pressing induces the 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 presentations of food induce adjunctive behaviors (Falk, 1971; 1977; Staddon, 1977) that compete with operant activities (Baum & Aparicio, 2020; Gutiérrez-Ferre & Pellón, 2019).

Concurrent-chains procedures have been successfully used to assess delay discounting in inbred strains of SHR and LEW rats (Aparicio, 2023; Aparicio et al., 2022). Choice is measured in the initial link with the allocation of presses on two levers (Grace, 1994; 1999). Two random interval (RI) schedules operate concurrently on two levers (conc RI-RI) arranging entries to two terminal links holding constant the rate of reinforcement (Stubbs & Pliskoff, 1969). One terminal link delivers 1-food pellet with a 0.1-s delay (the smaller-sooner food or SSF) and the other 4-food pellets with a delay of 0.1, 5, 10, 20, 40, or 80 s (the larger-later food or LLF). The delays to the LLF are selected in random order and presented during the session resembling Evenden's and Ryan (1996) method to obtain a discounting function in each session. Each food delivery (SSF or LLF) causes the retraction

of the lever that produced it, forcing the rat to travel from the front wall to the back wall of the chamber to press a non-retractable lever re-starting the initial link. Sensitivity of choice to increasing delay to the LLF increases with the travel requirement (Aparicio, 2023), because travel requires effort and effort influences choice (e.g., Aparicio, 2001; Aparicio & Cabrera, 2001; Ren et al., 2022; Salamone and Correa, 2009).

The aim of the present study is to show that food induces polydipsia in choice situations using concurrent-chain procedures with RI schedules in the initial link arranging entries to two terminal links, one delivering the SSF and the other delaying the delivery of the LLF. One goal is to demonstrate that SHR and LEW learn to choose impulsively with prolonged training in the choice situation. The LEW rats are expected to make more impulsive choices producing higher discounting rates at the beginning of training than the SHRs, but this difference in impulsive choice between strains should disappear at the end of training with the SHRs and LEWs showing similar discounting rates after developing polydipsia. The final goal is to extend the generality of findings showing that the performance of the SHR on concurrent-chains procedures varying the delay to the LLF is like the performance of the LEW (Aparicio, 2023; Aparicio et al., 2022).

## Method

### Subjects

Sixteen male rats, 8-SHR and 8-LEW (Charles River, Wilmington, MA), between 120-150 days old, were the subjects. All rats had experience on auto-shaping procedures establishing the acquisition and maintenance of lever pressing (Aparicio et al., 2020b), but none of the rats had experience with the present concurrent-chains procedure. Animals were housed individually in plastic cages with access to food and water constantly 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). One day before the study started, the food was removed from the cages leaving the rats on a food restriction regime, but there were no attempts to reduce their weights ranging from 286 to 310 g ( $M = 298$  g) for the SHRs and from 292 to 310 ( $M = 302$  g) for the LEWs. During the study, 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. The weights of the SHRs ranged from 294 to 386 g ( $M = 351$  g) at the end of the study, and the weights of the LEWs ranged from 392 to 417 g ( $M = 406$  g). Sessions were conducted daily at same time (12:00 PM). A veterinary (DVM, MS, DACLAM) supervised the rats' health. The Salem State University's Institutional Animal Care and Use Committee approved the research protocol (IACUC 011817-2) according to guidelines of NIH (No. 8023). This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors and it has no conflict of interest that should be reported.

### Apparatus

Eight modular chambers (E10-11R TC) for rats (Colbourn Instruments®), were used. Each chamber had two retractable levers (E23-17RA) mounted on the front wall 6 cm above the floor, one lever at 2.5 cm from the left wall and the other lever at 2.5 cm from the right wall. The mechanism for the extension and retraction of the levers took approximately 0.1 s. A third non-retractable 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 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 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 licks (contacts) to the metal spout of a bottle containing 100 ml of tap water. Two computers each linked to 4-chambers using Habitest Lincs (H02-08) delivered the stimuli and recorded responses executing Graphic State Notation (V 3.03) at a 0.01-s resolution.

## Procedure

The rats were directly exposed to a concurrent-chains procedure (Aparicio, 2023). Each session started with the house light turned on, the front levers retracted from the chamber, and the lights above them turned off. One press on the back-wall-non-retractable lever turned off the house light, extended the front levers into the chamber, and turned on the lights above the levers starting the initial link. Choice was measured in the initial link (Grace, 1999) with presses on the extended levers. The levers were linked to two non-independent random interval (RI) schedules averaging 11 s each, the intervals were created by a probability generator set to .05 and queried every second. The RI schedules functioned concurrently on the levers arranging an equal number of terminal link entries (conc RI 11 s RI 11 s), keeping constant the relative rate of reinforcement (Stubbs and Pliskoff, 1969). One RI schedule was associated to the left lever or SS-lever, and the other was associated to the right lever or LL-lever. When the RI schedule linked to the SS-lever arranged a terminal link entry, one press on the SS-lever started that terminal link retracting the LL-lever from the chamber and turning off the light above it. A second press on the SS-lever produced 1-food pellet (the SSF) with a slight delay (0.1 s) retracting the lever from the chamber, turning off the light above it, and turning on the house light. The rat moved from the front wall to the back wall of the chamber to press the nonretractable lever re-starting the initial link. Once the RI schedule linked to the LL-lever arranged a terminal link entry, one press on that lever started that terminal link, retracting the SS-lever from the chamber and turning off the light above it. Another press on the LL-lever started a delay (0.1, 5, 10, 20, 40, or 80 s) to get 4-food pellets (the LLF). The delay to LLF was selected from a list in random order and presented only one time during the session without replacement. The lever was not retracted from the chamber during the delay to LLF to prevent its retraction to function as a conditioned reinforcement (Fantino, 1969), pressing the lever during the delay to LLF had no scheduled consequences. The delivery of the LLF retracted the LL-lever from the chamber, turning off the light above it and turning on the house light. Again, the rat traveled from the front wall to the back wall of the chamber to press the non-retractable lever to re-start the initial link. When the rat obtained 10 foods, 5-SSF in one terminal link and 5-LLF with the delay randomly selected in the other terminal link, a 1-min blackout started with all lights turned off and the levers retracted from the chamber. At the end of the 1-min blackout, a different delay to the LLF was selected randomly from a list for the rat to obtain another 10 foods, 5-LLF in one terminal link and 5-SSF in the other terminal link. The session ended after sixty food deliveries, 30-SSF and 30-LLF, or it ended when ninety minutes elapsed whichever happened first. But most sessions ended with rats obtaining 60 foods with the delays to LLF defining six delay-components (Aparicio, 2023). For four rats of each strain the left lever was the SS-lever and the right lever the LL-lever. These conditions were reversed for the other four rats of each strain; the left lever was the LL-lever and the right lever the SS-lever to prevent a bias for one lever over the other lever.

## Experimental Design

An *ABA* reversal design controlled the availability of a bottle with water for the rats to drink during the session, *A* was a no-water condition ( $A_{NW1}$  and  $A_{NW2}$ ) and *B* a water condition ( $B_W$ ). In the first no water condition ( $A_{NW1}$ ), the bottle with water, the hopper attached to it, and the photo-operandum buffer recording licks were removed from the chamber; the rats responded to the concurrent-chains procedure for 150 consecutive sessions. In the water condition ( $B_W$ ), the bottle containing 100 ml of tap water, the hopper attached to it, and the photo-operandum buffer were placed in the chamber for the rats to respond to the concurrent-chains procedure for another 150 consecutive sessions. At the end of each session the bottle was removed from the chamber to measure milliliters of water remaining in the bottle, this volume was subtracted from 100 ml of water

available at the beginning of the session computing the milliliters of water consumed by each rat. The last no water condition ( $A_{NW2}$ ) removed the bottle with the water from the chamber, leaving the metal spout attached to the photo-operandum buffer to record licks during the session assessing the following possibilities. If water is necessary to maintain the behavior of licking the spout of the bottle, licking would not occur in the absence of water. But if licking is an activity induced by food, licking the spout of the bottle would occur in the absence of water. The rats responded to the concurrent-chains procedure for ninety consecutive sessions that were enough for their choices to show stability (no increasing or decreasing trends in proportions of LL choice in two blocks of sessions).

## Data Analysis

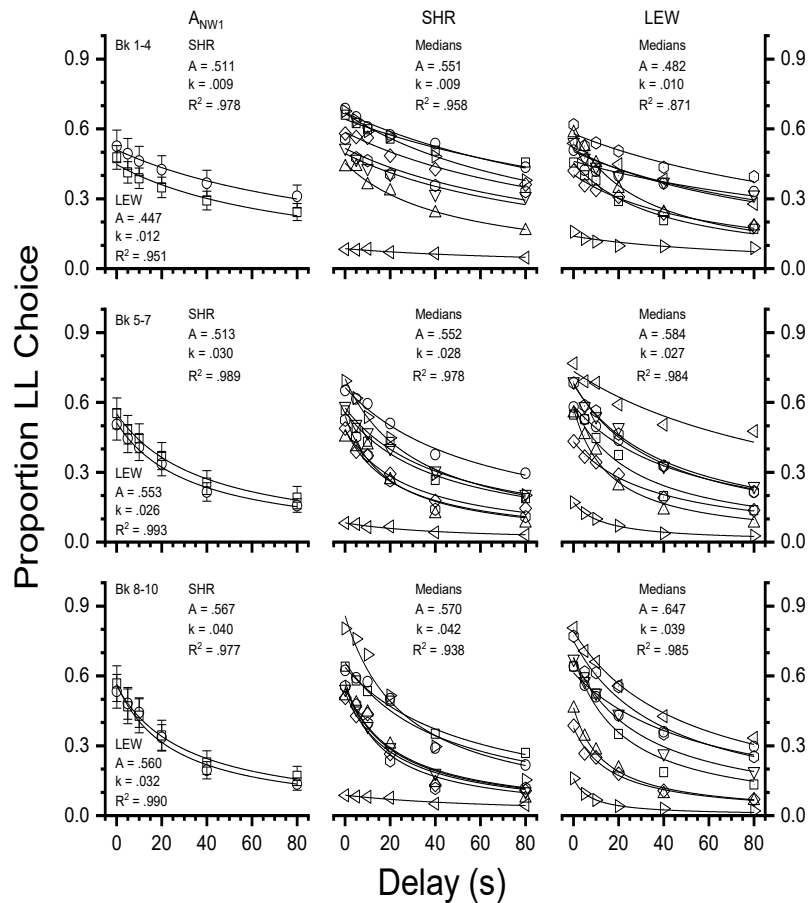
The data from all sessions of each condition were organized in blocks of fifteen sessions each and sorted by delay component, counting the total number of presses in the initial-link that each rat emitted on the lever linked to the SSF (SS-lever) and the total number of presses emitted on the lever linked to the LLF (LL-lever). With the computations obtained with fifteen sessions of each block, the medians of presses on the SS-lever and LL-lever were calculated for each rat and the group of rats of the same strain. Medians of presses were calculated instead of means of presses, because delay discounting data are not normally distributed (Myerson and Green, 1995). The medians of presses were used to compute the proportions of LL choice ((presses on the LL-lever / (presses on the LL-lever + presses on the SS-lever)) produced by each rat and the group of rats. Eq. 1 generated the discounting functions fitting changes in the proportions of LL choice that occurred as a function of changes in the delay to the LLF with two empirical parameters,  $k$  and  $A$ , where parameter  $A$  was free to vary (it was not assumed to be 1.0 LL choice at the y-intercept). Linear regression (the least-squares method) fitted milliliters of water consumed by the rats, licks to the spout of the bottle during blackouts, licks to the spout of the bottle before starting the initial link, licks to the spout of the bottle in the initial link, and licks to the spout of the bottle in the terminal link during the delay to the LLF. Because the 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, nonparametric paired sample Wilcoxon signed rank tests assessed between strain differences in estimates of  $A$ ,  $k$ , and the licks emitted to the spout of the bottle. Origin® provided curvilinear fitting, linear fitting, and nonparametric statistical tests at the alpha level of 0.05.

## Results

### *Discounting functions*

Figure 1 shows discounting functions produced by SHRs and LEWs in blocks of sessions 1 to 4 (top graphs), 5 to 7 (middle graphs), and 8 to 10 (bottom graphs) of condition ( $A_{NW1}$ ). All discounting functions show proportions of LL choice decreasing with the increasing delay to the LLF. The rats' preference for the LLF gradually switched to the SSF. Eq. 1 suitably fitted means of proportions of LL choice produced by SHRs and LEWs in blocks of sessions 1 to 4 ( $R^2 = .978$  and  $.951$ ), 5 to 7 ( $R^2 = .989$  and  $.993$ ), and 8 to 10 ( $R^2 = .977$  and  $.990$ ), respectively. Sensitivity of choice to magnitude of the LLF ( $A$  in Eq. 1) increased with the rats' experience in the choice situation. Discounting functions produced by the group of SHRs show estimates of  $A$  (.511, .513, and .567, respectively) comparable to estimates  $A$  computed for discounting functions produced by the group of LEWs (.447, .553, and .560, respectively). The discounting rate produced by the group of LEWs in blocks 1 to 4 ( $k = .012$ ) is greater than that produced by the group of SHRs ( $k = .009$ ), indicating that LEWs made more impulsive choices in blocks 1 to 4 than SHRs. But the discounting rates produced by the group of SHRs in blocks 5 to 7 and 8 to 10 ( $k = .030$  and  $.040$ , respectively) were greater than the discounting rates produced by the group of LEWs ( $k = .026$  and  $.032$ , respectively), demonstrating that the SHRs developed more impulsive choices in the last six blocks of sessions of condition  $A_{NW1}$  than the LEWs. Table 1 summarizes resulting parameters from Eq. 1 fitting proportions of LL choice produced by individuals and the group of SHR and LEW in condition  $A_{NW1}$ . Eq. 1 properly fitted proportions of LL choice produced by SHRs and LEWs in blocks of sessions 1 to 4 (*Mdn*  $R^2 = .958$  and  $.871$ ), 5 to 7 (*Mdn*  $R^2 = .978$  and  $.984$ ), and 8 to 10 (*Mdn*  $R^2 =$

.938 and .985), respectively. Estimates of sensitivity of choice to magnitude of the LLF ( $A$ ) for discounting functions produced by SHRs in blocks 1 to 4 ( $Mdn = .551$ , range from .086 to .670), were like ( $W = 23, p = .529$ ) estimates of sensitivity of choice for discounting functions produced by LEWs ( $Mdn = .482$ , range from .139 to .593). Similarly, estimates of  $A$  for discounting functions produced by SHRs in blocks 5 to 7 ( $Mdn = .552$ , range from .083 to .703) were equivalent ( $W = 12, p = .441$ ) to estimates of  $A$  for discounting functions produced by LEWs ( $Mdn = .584$ , range from .171 to .734). Correspondingly, estimates of  $A$  for discounting functions produced by SHRs in blocks 8 to 10 ( $Mdn = .570$ , range from .088 to .861), were like ( $W = 16, p = .834$ ) estimates of  $A$  for discounting functions produced by LEWs ( $Mdn = .647$ , range from .161 to .792). One rat of each strain shows poor sensitivity of choice to the magnitude of the LLF in blocks 1 to 4 ( $A = .086$  and .139), 5 to 7 ( $A = .083$  and .171), and 8 to 10 ( $A = .088$  and .161). Discounting rates ( $k$ ) produced by SHRs in blocks 1 to 4 ( $Mdn = .009$ , range from .006 to .021) were like ( $W = 11, p = .363$ ) discounting rates produced by LEWs ( $Mdn = .010$ , range from .006 to .033). Similarly, discounting rates produced by SHRs in blocks 5 to 7 ( $Mdn = .028$ , range from .016 to .053) were comparable ( $W = 16, p = .834$ ) to discounting rates produced by LEWs ( $Mdn = .027$ , range from .009 to .076). Lastly, discounting rates produced by SHRs in blocks 8 to 10 ( $Mdn = .042$ , range from .013 to .062) were like ( $W = 12, p = .779$ ) discounting rates produced by LEWs ( $Mdn = .039$ , range from .017 to .139).



**Figure 1.** Discounting functions produced by the SHRs and LEWs in the first no water condition ( $A_{NW1}$ ). Proportions of LL choice produced in blocks 1 to 4 (top graphs), 5 to 7 (middle graphs), and 8 to 10 (bottom graphs) are plotted as a function of the delay in seconds to obtain the LLF. The left column of graphs shows the means of proportions of LL choice computed for the group (SHR circles and LEW squares). Estimates of  $A$ ,  $k$ , and  $R^2$  from Eq. 1 appear near to lines of best

fit. The central and right columns of graphs show the proportions of LL choice produced by the individual SHRs and LEW's (various symbols) and medians of  $\mathcal{A}$ ,  $k$  and  $R^2$  from fits of Eq. 1.

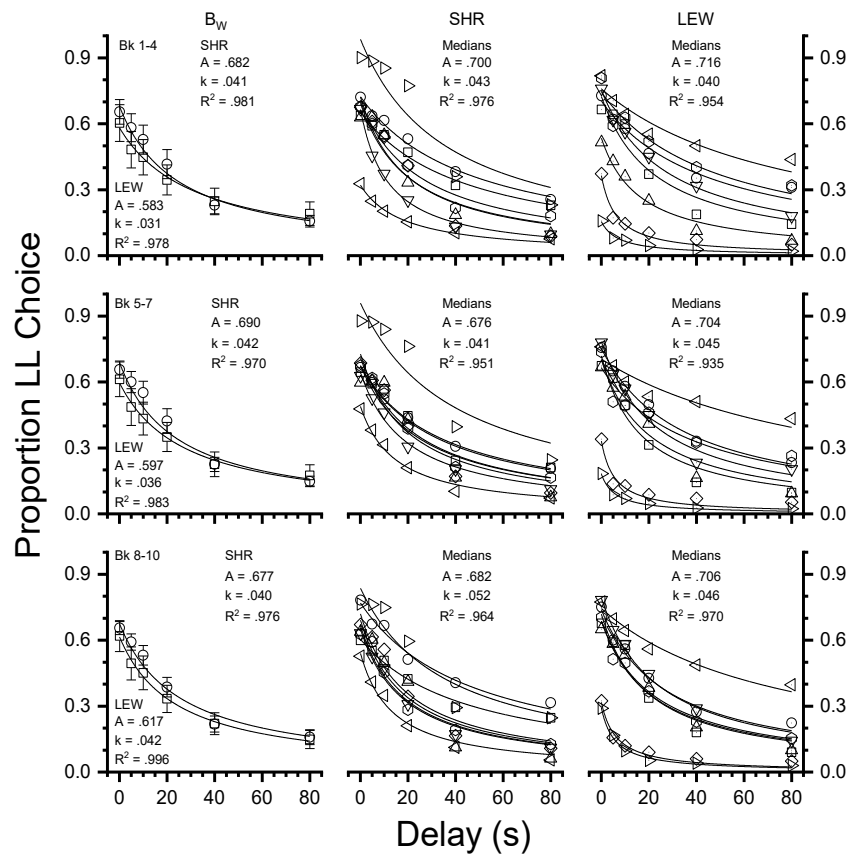
**Table 1.**

Hyperbolic-decay model, resulting parameters from condition  $A_{NW1}$ .

Rat	$\mathcal{A}$		$k$		$R^2$	
	SHR	LEW	SHR	LEW	SHR	LEW
Blocks 1 to 4						
1	0.642	0.456	0.006	0.026	0.948	0.979
2	0.670	0.461	0.007	0.006	0.968	0.746
3	0.453	0.593	0.021	0.033	0.970	0.989
4	0.495	0.503	0.010	0.009	0.873	0.860
5	0.586	0.404	0.008	0.017	0.967	0.975
6	0.086	0.511	0.009	0.010	0.928	0.894
7	0.667	0.139	0.010	0.011	0.989	0.661
8	0.516	0.579	0.009	0.007	0.837	0.865
<b>Group</b>	0.511	0.447	0.009	0.012	0.978	0.951
Blocks 5 to 7						
1	0.665	0.582	0.016	0.035	0.982	0.952
2	0.560	0.586	0.024	0.020	0.956	0.992
3	0.487	0.577	0.043	0.062	0.891	0.974
4	0.577	0.678	0.022	0.024	0.997	0.979
5	0.482	0.432	0.035	0.028	0.975	0.989
6	0.083	0.734	0.021	0.009	0.927	0.882
7	0.703	0.171	0.031	0.076	0.994	0.996
8	0.544	0.684	0.053	0.026	0.981	0.991
<b>Group</b>	0.513	0.553	0.030	0.026	0.989	0.993
Blocks 8 to 10						
1	0.638	0.683	0.018	0.046	0.987	0.950
2	0.659	0.614	0.023	0.017	0.929	0.952
3	0.558	0.466	0.046	0.073	0.914	0.989
4	0.555	0.680	0.047	0.032	0.996	0.988
5	0.532	0.380	0.047	0.060	0.922	0.982
6	0.088	0.792	0.013	0.020	0.913	0.988
7	0.861	0.161	0.038	0.139	0.946	0.992
8	0.582	0.751	0.062	0.025	0.954	0.955
<b>Group</b>	0.567	0.560	0.040	0.032	0.977	0.990

Figure 2 shows discounting functions produced by SHRs and LEW's in condition (B<sub>w</sub>). All discounting functions have hyperbolic shape, proportions of LL choice produced by SHRs are comparable to proportions of LL choice produced by LEW's. Both strains of rats show proportions of LL choice decreasing gradually with the increasing delay to LLF, indicating that preference for the LLF switched to the SSF. Lines fitting proportions of LL choice produced by the group of SHRs overlap with lines fitting proportions of LL choice produced by the group LEW's, indicating that impulsive choices made by SHRs were like impulsive choices made by LEW's. Eq. 1 fitted the proportions of LL choice produced by SHRs and LEW's in blocks of sessions 1 to 4 ( $R^2 = .981$  and  $.978$ ), 5 to 7 ( $R^2 = .970$  and  $.983$ ), and 8 to 10 ( $R^2 = .976$  and  $.996$ ), respectively. Sensitivity of choice to magnitude of LLF ( $\mathcal{A}$ ) for discounting functions produced by SHRs in blocks 1 to 4, 5 to 7, and 8 to 10 ( $\mathcal{A} = .682$ ,  $.690$ , and  $.677$  respectively), was greater than that corresponding to discounting functions produced by LEW's ( $\mathcal{A} = .583$ ,  $.597$ , and  $.617$ , respectively). Discounting rates produced

by SHRs in blocks 1 to 4 and blocks 5 to 7 ( $k = .041$  and  $.042$ , respectively), were greater than discounting rates produced by LEWs ( $k = .031$  and  $.036$ , respectively). But the discounting rate produced by SHRs in blocks 8 to 10 ( $k = .040$ ) was like the discounting rate produced by LEWs ( $k = .042$ ), indicating that SHRs and LEWs made similar impulsive choices in the last three blocks of condition B<sub>w</sub>. Table 2 summarizes resulting parameters from Eq. 1 fitting proportions of LL choice produced by individuals and the group of rats of each strain in condition B<sub>w</sub>. Eq. 1 accurately fitted proportions of LL choice produced by individual SHR and LEW in blocks 1 to 4 (*Mdn*  $R^2 = .976$  and  $.954$ ), 5 to 7 (*Mdn*  $R^2 = .951$  and  $.935$ ) and 8 to 10 (*Mdn*  $R^2 = .964$  and  $.970$ ), respectively. Estimates of  $A$  for discounting functions produced by SHRs in blocks 1 to 4 (*Mdn* = .700, range from .322 to .987), were like ( $W = 20, p = .834$ ) estimates of  $A$  corresponding to discounting functions produced by LEWs (*Mdn* = .716, range from .157 to .759). Equally, estimates of  $A$  for discounting functions produced by SHRs in blocks 5 to 7 (*Mdn* = .676, range from .492 to .961) were comparable ( $W = 17, p = .944$ ) to estimates of  $A$  for discounting functions produced by LEWs (*Mdn* = .704, range from .184 to .786). Congruently, estimates of  $A$  for discounting functions produced by SHRs in blocks 8 to 10 (*Mdn* = .682, range from .544 to .838) were like ( $W = 19, p = .944$ ) estimates of  $A$  for discounting functions produced by LEWs (*Mdn* = .706, range from .297 to .795). Discounting rates produced by SHRs in blocks 1 to 4 (*Mdn* = .043, range from .021 to .087) were similar ( $W = 14, p = .624$ ) to discounting rates produced by LEWs (*Mdn* = .040, range from .012 to .162). Correspondingly, discounting rates produced by SHRs in blocks 5 to 7 (*Mdn* = .041, range from .025 to .067) were comparable ( $W = 12, p = .441$ ) to discounting rates produced by LEWs (*Mdn* = .045, range from .010 to .186). Lastly, discounting rates produced by SHRs in blocks 8 to 10 (*Mdn* = .052, range from .021 to .073) were comparable ( $W = 12, p = .441$ ) to discounting rates produced by LEWs (*Mdn* = .046, range from .013 to .182).



**Figure 2.** Discounting functions produced by the SHRs and LEWs in the water condition (BW). Other details as in Fig. 1.

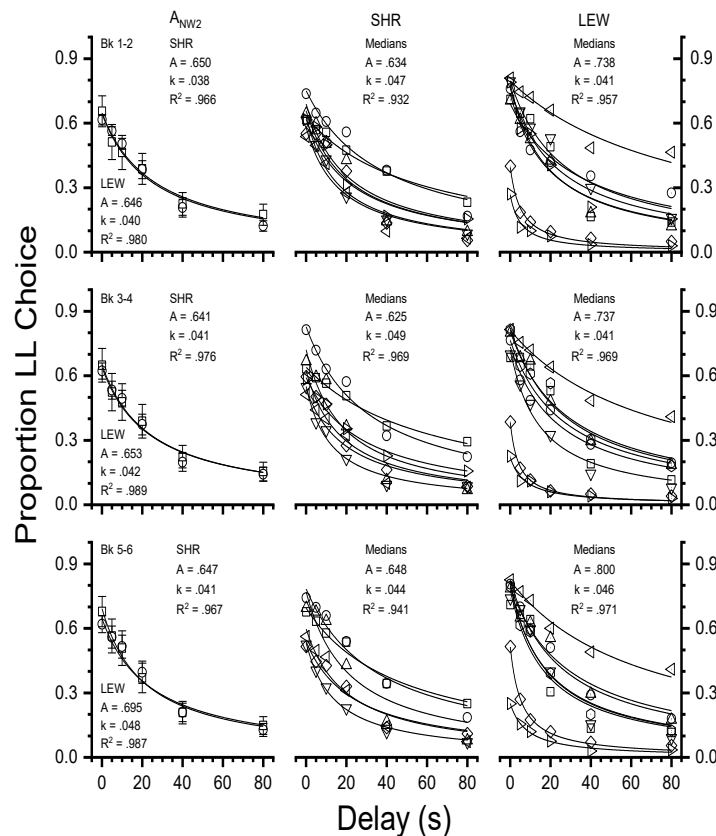
**Table 2.**

Hyperbolic-decay model, resulting parameters from condition B<sub>w</sub>.

Rat	<i>A</i>		<i>k</i>		<i>R</i> <sup>2</sup>	
	SHR	LEW	SHR	LEW	SHR	LEW
Blocks 1 to 4						
1	0.654	0.727	0.023	0.044	0.986	0.906
2	0.725	0.705	0.021	0.022	0.988	0.953
3	0.696	0.538	0.047	0.062	0.905	0.969
4	0.671	0.754	0.087	0.036	0.995	0.994
5	0.725	0.370	0.051	0.162	0.907	0.956
6	0.322	0.759	0.054	0.012	0.989	0.860
7	0.987	0.157	0.027	0.140	0.855	0.974
8	0.703	0.745	0.039	0.021	0.965	0.890
<b>Group</b>	0.682	0.583	0.041	0.031	0.981	0.978
Blocks 5 to 7						
1	0.674	0.723	0.030	0.061	0.941	0.944
2	0.673	0.755	0.028	0.029	0.998	0.994
3	0.678	0.703	0.039	0.048	0.822	0.926
4	0.646	0.786	0.051	0.043	0.987	0.976
5	0.731	0.338	0.049	0.186	0.927	0.915
6	0.492	0.705	0.067	0.010	0.984	0.830
7	0.961	0.184	0.025	0.175	0.870	0.978
8	0.711	0.666	0.041	0.026	0.962	0.859
<b>Group</b>	0.690	0.597	0.042	0.036	0.970	0.983
Blocks 8 to 10						
1	0.606	0.722	0.022	0.052	0.979	0.923
2	0.770	0.741	0.021	0.037	0.973	0.981
3	0.695	0.690	0.053	0.044	0.876	0.949
4	0.654	0.795	0.053	0.042	0.976	0.989
5	0.723	0.322	0.051	0.161	0.927	0.958
6	0.544	0.745	0.073	0.013	0.978	0.960
7	0.838	0.297	0.027	0.182	0.876	0.989
8	0.668	0.690	0.053	0.047	0.955	0.979
<b>Group</b>	0.677	0.617	0.040	0.042	0.976	0.996

Figure 3 shows proportions of LL choice produced by SHRs and LEWs in condition A<sub>NW2</sub>. Discounting functions produced by the group of SHRs are like those produced by the group of LEWs, showing data points and lines of best fit to proportions of LL choice produced by SHRs overlapping with those corresponding to proportions of LL choice produced by LEWs. Both strains of rats made impulsive choices producing discounting functions with hyperbolic shape, showing proportions of LL choice decreasing with the increasing delay to the LLF. Eq. 1 nicely fitted proportions of LL choice produced by SHRs and LEWs in blocks of sessions 1 to 2 ( $R^2 = .966$  and  $.980$ , respectively), 3 to 4 ( $R^2 = .976$  and  $.989$ , respectively) and 5 to 6 ( $R^2 = .967$  and  $.987$ , respectively). Estimates of sensitivity of choice to the magnitude of the LLF for the discounting functions produced by SHRs in blocks 1 to 2, 3 to 4, and 5 to 6 ( $A = .650$ ,  $.641$ , and  $.647$ , respectively), were like those corresponding to discounting functions produced by LEWs ( $A = .646$ ,  $.653$ , and  $.695$ , respectively). Discounting rates produced by SHRs in blocks 1 to 2 and 3 to 4 ( $k = .038$  and  $.041$ , respectively) were like those produced by LEWs ( $k = .040$  and  $.042$ , respectively). But the discounting rate ( $k = .048$ ) produced by LEWs in blocks 5 to 6, was greater than the discounting

rate produced by SHRs ( $k = .041$ ), indicating that LEWs discounted the LLF more than SHRs in the last two blocks of sessions of condition  $A_{NW2}$ . Table 3 shows the resulting parameters from Eq. 1 fitting proportions of LL choice produced by individuals and the group of each strain of rats in condition  $A_{NW2}$ . Parameters calculated for discounting functions produced by individual SHRs are comparable to those computed for the discounting functions produced by individual LEWs. Eq. 1 nicely fitted proportions of LL choice produced by SHRs and LEWs in blocks 1 to 2 ( $Mdn R^2 = .932$  and  $.957$ ), 3 to 4 ( $Mdn R^2 = .969$  and  $.969$ ), 5 to 6 ( $Mdn R^2 = .941$  and  $.971$ ), respectively. Estimates of  $A$  for discounting functions produced by SHRs in blocks 1 to 2 ( $Mdn = .634$ , range from  $.582$  to  $.752$ ) were like ( $W = 15, p = .933$ ) estimates of  $A$  for discounting functions produced by LEWs ( $Mdn = .738$ , range from  $.270$  to  $.798$ ). Similarly, estimates of  $A$  for discounting functions produced by SHR rats in blocks 3 to 4 ( $Mdn = .625$ , range from  $.540$  to  $.830$ ) were equivalent ( $W = 13, p = .933$ ) to estimates of  $A$  for discounting functions produced by LEWs ( $Mdn = .737$ , range from  $.223$  to  $.826$ ). Congruently, estimates of  $A$  for discounting functions produced by SHRs in blocks 5 to 6 ( $Mdn = .648$ , range from  $.536$  to  $.785$ ) were similar ( $W = 1, p = .059$ ) to estimates of  $A$  for the discounting functions produced by LEWs ( $Mdn = .800$ , range from  $.522$  to  $.823$ ). Impulsive choices made by SHRs were comparable to impulsive choices made by LEWs. Discounting rates produced by SHRs in blocks 1 to 2 ( $Mdn = .047$ , range from  $.018$  to  $.063$ ) were like ( $W = 9, p = .447$ ) discounting rates produced by LEWs ( $Mdn = .041$ , range from  $.011$  to  $.190$ ). Similarly, discounting rates produced by SHRs in blocks 3 to 4 ( $Mdn = .049$ , range from  $.016$  to  $.079$ ) were like ( $W = 10, p = .554$ ) discounting rates produced by LEWs ( $Mdn = .041$ , range from  $.014$  to  $.242$ ). Lastly, discounting rates produced by SHR rats in blocks 5 to 6, ( $Mdn = .044$ , range from  $.021$  to  $.070$ ) were like ( $W = 9, p = .834$ ) discounting rates produced by LEWs ( $Mdn = .046$ , range from  $.015$  to  $.182$ ).



**Figure 3.** Discounting functions produced by the SHRs and LEWs in blocks 1 to 2 (top graphs), 3 to 4 (middle graphs), and 5 to 6 (bottom graphs) of the last no water condition  $A_{NW2}$ . Other details as in Fig. 1.

**Table 3.**

Hyperbolic-decay model, resulting parameters from condition  $A_{NW2}$ .

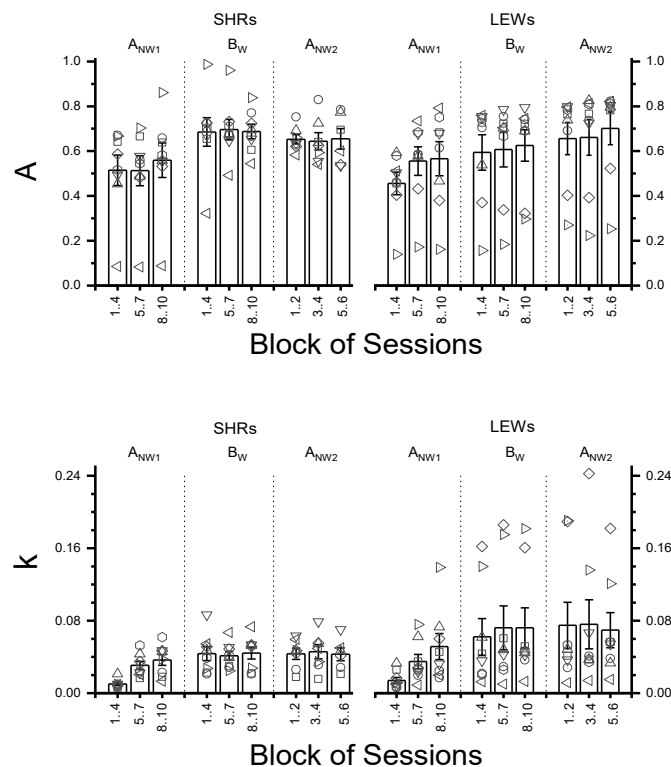
Rat	$A$		$k$		$R^2$	
	SHR	LEW	SHR	LEW	SHR	LEW
Blocks 1 to 2						
1	0.629	0.763	0.018	0.041	0.979	0.877
2	0.752	0.691	0.026	0.028	0.938	0.858
3	0.692	0.738	0.047	0.048	0.899	0.952
4	0.634	0.798	0.063	0.037	0.976	0.965
5	0.620	0.403	0.044	0.189	0.844	0.977
6	0.582	0.797	0.059	0.011	0.920	0.918
7	0.660	0.270	0.047	0.190	0.932	0.962
8		0.785		0.053		0.975
<b>Group</b>	0.650	0.646	0.038	0.040	0.966	0.980
Blocks 3 to 4						
1	0.641	0.766	0.016	0.037	0.980	0.836
2	0.830	0.737	0.031	0.041	0.969	0.970
3	0.724	0.826	0.055	0.037	0.875	0.969
4	0.555	0.725	0.079	0.067	0.975	0.974
5	0.625	0.393	0.055	0.242	0.956	0.990
6	0.540	0.813	0.049	0.014	0.904	0.979
7	0.593	0.223	0.035	0.136	0.988	0.955
8		0.809		0.034		0.945
<b>Group</b>	0.641	0.653	0.041	0.042	0.976	0.989
Blocks 5 to 6						
1	0.696	0.782	0.021	0.057	0.967	0.859
2	0.785	0.823	0.028	0.038	0.954	0.983
3	0.773	0.796	0.047	0.033	0.867	0.945
4	0.536	0.804	0.070	0.054	0.993	0.915
5	0.539	0.522	0.041	0.182	0.928	0.994
6	0.600	0.822	0.050	0.015	0.929	0.971
7		0.253		0.121		0.988
8		0.812		0.056		0.971
<b>Group</b>	0.647	0.695	0.041	0.048	0.967	0.987

The next analysis explored Grosch’s and Neuringer idea (1981) that organisms are more likely to wait for LLF when engaging in other activities (e.g., drinking water or licking the spout of the bottle) is allowed during the delay to obtain LLF. Figure 4 shows computations of  $A$  and  $k$  for discounting functions produced by SHRs and LEWs in conditions  $A_{NW1}$ ,  $B_W$ , and  $A_{NW2}$ . The multiple symbols are computations for the individuals and bars computations for the group. The upper-left graph shows estimates of  $A$  for discounting functions produced by SHRs in sessions of condition  $B_W$  ( $Mdn = .687$ , range from .322 to .987), greater ( $W = 293, p < .0001$ ) than estimates of  $A$  for discounting functions produced in sessions of condition  $A_{NW1}$  ( $Mdn = .559$ , range from .083 to .861). Similarly, estimates of  $A$  for discounting functions produced by SHRs in sessions of  $A_{NW2}$  ( $Mdn = .632$ , range from .536 to .830) are greater ( $W = 181, p = .004$ ) than estimates of  $A$  computed in sessions of  $A_{NW1}$ . But estimates of  $A$  for discounting functions produced by SHRs in sessions of  $B_W$  are like ( $W = 125, p = .467$ ) those computed in sessions of  $A_{NW2}$ .

The upper-right graph shows estimates of  $A$  for discounting functions produced by LEWs in sessions of  $B_W$  ( $Mdn = .705$ , range from .157 to .795) greater ( $W = 243, p = .008$ ) than those corresponding

to sessions of  $A_{NW1}$  ( $Mdn = .578$ , range from  $.139$  to  $.792$ ). Also, estimates of  $\mathcal{A}$  for discounting functions produced by LEWs in sessions of  $A_{NW2}$  ( $Mdn = .774$ , range from  $.223$  to  $.856$ ), are greater ( $W = 296, p < .0001$ ) than estimates of  $\mathcal{A}$  for discounting functions produced in sessions of  $A_{NW1}$ . Uniformly, estimates of  $\mathcal{A}$  for discounting functions produced by LEWs in sessions of  $A_{NW2}$  are greater ( $W = 271, p < .0001$ ) than those corresponding to sessions of  $B_W$ . So, the choices made by SHRs and LEWs showed higher sensitivity to the magnitude of the LLF (greater values of  $\mathcal{A}$ ) in sessions of conditions  $B_W$  and  $A_{NW2}$  than in sessions of condition  $A_{NW1}$ .

The lower-left graph shows discounting rates produced by SHRs in sessions of  $B_W$  ( $Mdn = .044$ , range from  $.021$  to  $.087$ ), greater ( $W = 259, p < .001$ ) than discounting rates produced in sessions of  $A_{NW1}$  ( $Mdn = .022$ , range from  $.006$  to  $.062$ ). Equally, discounting rates produced by SHRs in sessions of  $A_{NW2}$  ( $Mdn = .047$ , range from  $.016$  to  $.079$ ) are greater ( $W = 203, p < .0001$ ) than those produced in sessions of  $A_{NW1}$ . But discounting rates produced by SHRs in sessions of  $B_W$  are like ( $W = 103, p = .955$ ) discounting rates produced in sessions of  $A_{NW2}$ . The lower-right graph shows discounting rates produced by LEWs in sessions of  $B_W$  ( $Mdn = .044$ , range from  $.010$  to  $.186$ ), greater ( $W = 267, p < .0001$ ) than discounting rates produced in sessions of  $A_{NW1}$  ( $Mdn = .025$ , range from  $.006$  to  $.139$ ). Equally, discounting rates produced by LEWs in sessions of  $A_{NW2}$  ( $Mdn = .045$ , range from  $.011$  to  $.242$ ) are greater ( $W = 237, p = .002$ ) than those produced in sessions of  $A_{NW1}$ . But discounting rates produced by LEWs in sessions of  $B_W$  are like ( $W = 107, p = .224$ ) discounting rates produced in sessions of  $A_{NW2}$ . Summarizing, SHRs and LEWs produced higher discounting rates ( $k$ ) and developed more sensitivity of choice to the magnitude of LLF ( $\mathcal{A}$ ) in sessions of conditions  $B_W$  and  $A_{NW2}$  than in sessions of condition  $A_{NW1}$ , challenging Grosch's and Neuringer idea (1981) that organisms are more likely to wait for LLF when engaging in other activities (drinking water or licking) is allowed during the delay to obtain LLF.



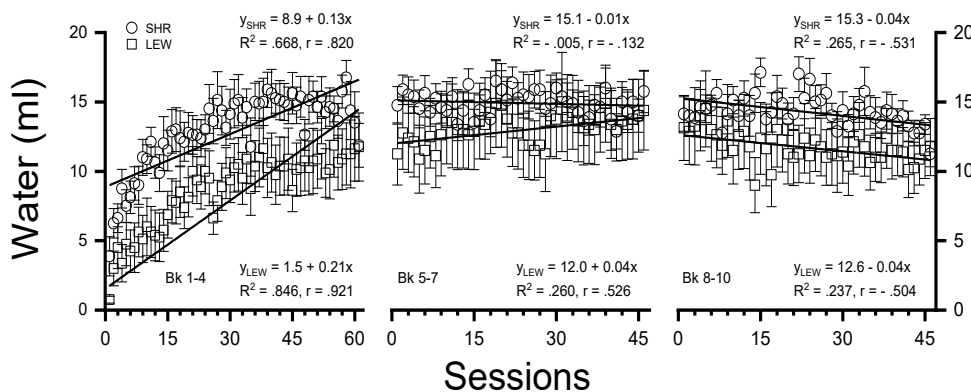
**Figure 4.** Estimates of  $\mathcal{A}$  (top graphs) and  $k$  (bottom graphs) for the discounting functions produced by the SHRs (left graphs) and LEWs (right graphs) in conditions  $A_{NW1}$ ,  $B_W$ , and  $A_{NW2}$  plotted against blocks of sessions. The different symbols are estimates for the discounting functions produced by the individual LEWs and SHRs and the bars the mean of the group

**Polydipsia**

The SHR and LEW rats developed polydipsia in condition B<sub>w</sub>. The milliliters of water consumed by each rat were recorded in each session and averaged across rats of the same strain to compute means of milliliters of water consumed by the group. Figure 5 shows the means of milliliters of water consumed by SHR and LEW rats in sessions of blocks 1 to 4 (left graph), 5 to 7 (central graph), and 8 to 10 (right graph). The milliliters of water consumed by SHR rats in sessions of blocks 1 to 4 (*Mdn* = 13.6, range from 3.9 to 16.8), are greater ( $W = 1891, p < .0001$ ) than the milliliters of water consumed by LEW rats (*Mdn* = 9.8, range from 0.8 to 11.9). Linear regression fitting milliliters of water consumed by SHR rats ( $R^2 = .668$ ) and LEW rats ( $R^2 = .846$ ), shows positive correlations between milliliters of water consumed and sessions of block 1 to 4 ( $r = .820$  and  $.921$ , respectively). The slope of the line fitting milliliters of water consumed by LEW rats ( $0.21x$ ) is steeper than the slope of the line fitting milliliters of water consumed by SHR rats ( $0.13x$ ), showing that milliliters of water consumed by LEW rats increased faster across sessions of blocks 1-4 than milliliters of water consumed by SHR rats.

Milliliters of water consumed by SHR rats in sessions of blocks 5 to 7 (*Mdn* = 15.0, range from 12.9 to 16.5) are greater ( $W = 1028, p < .0001$ ) than milliliters of water consumed by LEW rats (*Mdn* = 13.3, range from 10.9 to 15.0). Both strains of rats developed minor changes in means of milliliters of water consumed in sessions of blocks 5 to 7, resulting in poor fits of linear regression ( $R^2 = -.005$  and  $.260$ , respectively). Means of milliliters of water consumed by SHR rats show a negative correlation with sessions of blocks 5 to 7 ( $r = -.132$ ) and means of milliliters of water consumed by LEW rats show a positive correlation with sessions of blocks 5 to 7 ( $r = .526$ ). The slope of line fitting milliliters of water consumed by LEW rats ( $.04x$ ) is steeper than the slope of the line fitting milliliters of water consumed by SHR rats ( $-.01x$ ), indicating that milliliters of water consumed by LEW rats increased faster in sessions of blocks 5 to 7 than milliliters of water consumed by SHR rats.

Milliliters of water consumed by SHR rats in sessions of blocks 8 to 10 (*Mdn* = 14.1, range from 11.3 to 17.1) are greater ( $W = 1077, p = .0001$ ) than milliliters of water consumed by LEW rats (*Mdn* = 11.7, range from 9.0 to 14.5). Linear regression fitting milliliters of water consumed by SHR and LEW rats ( $R^2 = .265$  and  $.237$ , respectively), indicates negative correlations between milliliters of water consumed and sessions of blocks 8 to 10 ( $r = -.531$  and  $-.504$ , respectively). The slopes of the lines are identical ( $-.04x$ ) suggesting that the milliliters of water consumed by SHR and LEW rats decreased similarly across sessions of blocks 8 to 10.



**Figure 5.** Milliliters of water consumed by the SHR and LEW rats in sessions of blocks 1 to 4 (left graph), 5 to 7 (central graph), and 8 to 10 (right graph) of condition B<sub>w</sub>. The lines are the best fits from linear regression to milliliters of water consumed by the group of SHR rats (circles) and the group of LEW rats (squares). The corresponding equations ( $Y_{SHR}$  and  $Y_{LEW}$ ) appear near to the regression lines.

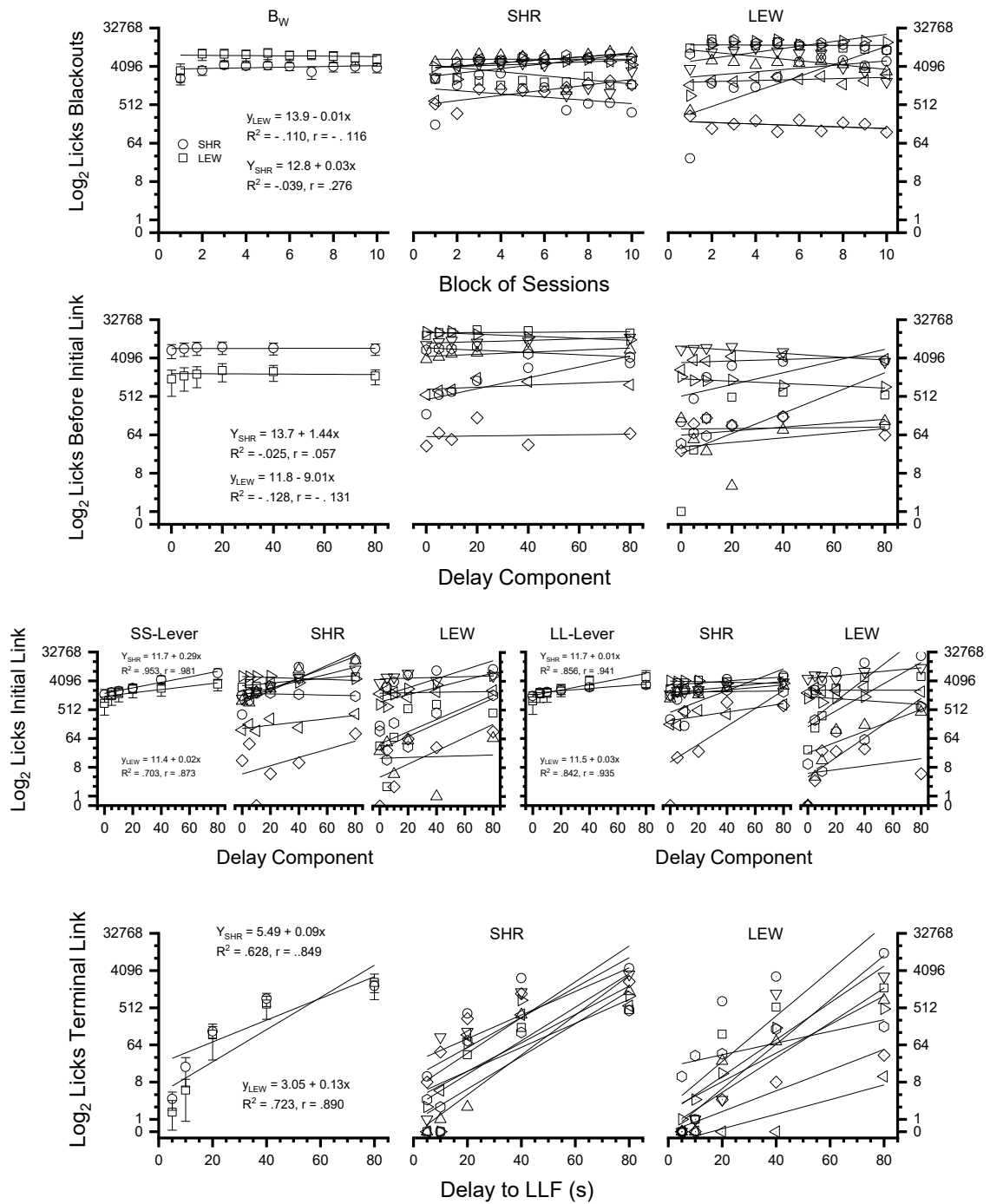
The next analyses looked at licks emitted to the spout of the bottle in blackout periods separating delay components, licks before the initial link, licks in the initial link after pressing the SS-lever and LL-lever, and licks in the terminal link during each delay to the LLF. Figure 6 shows licks emitted by SHRs and LEWs in condition B<sub>w</sub>. The top row of graphs shows licks emitted by the group of LEWs in blackouts (Mdn = 7582, range from 3207 to 8312), greater ( $W = 55, p = .002$ ) than licks emitted by the group of SHRs (Mdn = 4057, range from 2120 to 4422). Both strains of rats showed minimal changes in licks across block of sessions resulting in poor fits of linear regression to licks in blackouts ( $R^2 = -.110$ , and  $-.039$ , respectively). The slope of line fitting licks emitted by SHRs ( $0.03x$ ) is steeper than the slope of the line fitting licks emitted by LEWs ( $-0.01x$ ), showing licks emitted by SHRs increasing faster across blocks of sessions than licks emitted by LEWs. Licks emitted by SHRs show a positive correlation with blocks of sessions ( $r = .276$ ) and licks emitted by LEWs a negative correlation with blocks of sessions ( $r = -.166$ ). Linear fits to licks emitted by individual SHRs (central graph) generated  $R^2$  ranging from  $-.125$  to  $.588$  (Mdn =  $.192$ ) and linear fits to licks emitted by individual LEWs (right graph)  $R^2$  ranging from  $-.123$  to  $1.0$  (Mdn =  $.153$ ). Licks emitted by LEWs (Mdn = 5325, range from 28 to 17924) are greater ( $W = 2494, p < .0001$ ) than licks emitted by SHRs (Mdn = 3943, range from 173 to 8889). Slopes of lines fitting licks emitted by individual SHRs (Mdn =  $.10x$ , range from  $-0.16x$  to  $0.21x$ ), are equivalent ( $W = 20, p = .834$ ) to slopes of lines fitting licks emitted by individual LEWs (Mdn =  $.02x$ , range from  $-0.17x$  to  $0.59x$ ). Correlations between licks emitted by individual SHRs and blocks of sessions (Mdn =  $.489$ , range from  $-.489$  to  $.796$ ) are like ( $W = 23, p = .529$ ) correlations corresponding to licks emitted by individual LEWs (Mdn =  $.156$ , range from  $-1.0$  to  $.760$ ).

The second row of graphs shows licks emitted by SHRs and LEWs before starting the initial link plotted against delay components. Licks emitted by the group of SHRs (Mdn = 9627, range from 6219 to 7366) are greater ( $W = 21, p = .036$ ) than licks emitted by the group of LEWs (Mdn = 1928, range from 1317 to 2082). Both groups of rats developed slight changes in licks across delay components, resulting in poor fits of linear regression to fits emitted by SHRs and LEWs ( $R^2 = -.025$  and  $-.128$ , respectively). The slope of the line fitting licks emitted by the group of SHRs ( $1.44x$ ) shows licks increasing gradually across delay components, and the slope of the line fitting licks emitted by the group of LEWs shows licks decreasing rapidly across delay components ( $-9.01x$ ). Licks emitted by the group of SHRs developed a positive correlation with delay components ( $r = .057$ ) and licks emitted by the group of LEWs a negative correlation with delay components ( $r = -.131$ ). Licks emitted by individual SHRs (Mdn = 5869, range from 35 to 18940) are greater ( $W = 1012, p < .0001$ ) than licks emitted by individual LEWs (Mdn = 520, range from 1 to 7575). Linear fits to licks emitted by individual SHRs generated  $R^2$  ranging from  $-.240$  to  $.901$  (Mdn =  $.621$ ) and linear fits to the licks emitted by individual LEWs  $R^2$  ranging from  $-.245$  to  $.795$  (Mdn =  $.259$ ). Slopes of the lines fitting licks emitted by SHRs (Mdn =  $.01x$ , range from  $-0.01$  to  $0.04$ ) are like ( $W = 11, p = .363$ ) slopes of the lines fitting licks emitted by LEWs (Mdn =  $.01x$ , range from  $-0.01$  to  $0.08$ ). Correlations between licks emitted by individual SHRs and delay components (Mdn =  $.355$ , range from  $-.959$  to  $.869$ ) are like ( $W = 21, p = .726$ ) correlations corresponding to licks emitted by individual LEWs (Mdn =  $.372$ , range from  $-.914$  to  $.717$ ).

The third row of graphs shows licks emitted by SHRs and LEWs in the initial link after pressing the SS-lever (left graphs) and LL-lever (right graphs) plotted against delay components. Licks emitted by the group of SHRs after pressing the SS-lever (Mdn = 2211, range from 1535 to 7221) are like ( $W = 21, p = .036$ ) licks emitted by the group of LEWs after pressing the SS-lever (Mdn = 1993, range from 802 to 3251). Similarly, licks emitted by the group of SHRs after pressing the LL-lever (Mdn = 1954, range from 1366 to 3056) are like ( $W = 8, p = .675$ ) licks emitted by the group of LEWs after pressing the LL-lever (Mdn = 1942, range from 955 to 5523). Licks emitted by the group of SHRs after pressing the SS-lever are like ( $W = 713, p = .202$ ) licks emitted after pressing the LL-lever. Similarly, licks emitted by the group of LEWs after pressing the SS-lever are like ( $W = 385, p = .059$ ) licks emitted after pressing the LL-lever. Linear regression fitting licks emitted by the group of SHRs after pressing the SS-lever and LL-lever, did a better job ( $R^2 = .953$  and  $.856$ , respectively) than fitting licks emitted by the group of LEWs after pressing the SS-lever and LL-lever ( $R^2 = .703$  and  $.842$ , respectively). The slope of the line ( $0.29x$ ) fitting licks emitted by the group of SHRs after pressing the SS-lever, is steeper than that of the line ( $0.02x$ ) fitting licks emitted by the

group of LEWs after pressing the SS-lever. Nevertheless, the slope of the line ( $0.03x$ ) fitting licks emitted by the group of LEWs after pressing the LL-lever is like the slope of the line fitting licks emitted by the group of SHRs after pressing the LL-lever ( $0.01x$ ). Correlations between licks emitted by the group of SHRs after pressing the SS-lever and LL-lever and delay components ( $r = .981$  and  $.941$ , respectively), are like correlations computed with licks emitted by the group of LEWs after pressing the SS-lever and LL-lever ( $r = .873$  and  $.935$ , respectively). The licks emitted by individual SHRs after pressing the SS-lever (Mdn = 1769, range from 0 to 18672) are comparable ( $W = 778$ ,  $p = .051$ ) to licks emitted by individual LEWs (Mdn = 704, range from 0 to 9627). Correspondingly, licks emitted by individual SHRs after pressing the LL-lever (Mdn = 1934, range from 0 to 5903) are comparable ( $W = 543$ ,  $p = .983$ ) to licks emitted by individual LEWs (Mdn = 1003, range from 0 to 24536). Linear fits to licks emitted by individual SHRs after pressing the SS-lever generated  $R^2$  ranging from  $.055$  to  $.934$  (Mdn =  $.586$ ) and linear fits to licks emitted by individual LEWs  $R^2$  ranging from  $-.246$  to  $.795$  (Mdn =  $.243$ ). Respectively, linear fits to licks emitted by individual SHRs after pressing the LL-lever generated  $R^2$  ranging from  $-.183$  to  $.910$  (Mdn =  $.516$ ) and linear fits to licks emitted by individual LEWs  $R^2$  ranging from  $-.250$  to  $.695$  (Mdn =  $.281$ ). Slopes of lines fitting licks emitted by individual SHRs after pressing the SS-lever (Mdn =  $.03x$ , range from  $-0.00$  to  $0.07$ ), are like ( $W = 13$ ,  $p = .529$ ) slopes of lines fitting licks emitted by the individual LEWs after pressing the SS-lever (Mdn =  $.04x$ , range from  $0.00$  to  $0.07$ ). Slopes of lines fitting licks emitted by individual LEWs after pressing the LL-lever (Mdn =  $0.04x$ , range from  $-0.01$  to  $0.11$ ), are like ( $W = 13$ ,  $p = .529$ ) slopes of lines fitting licks emitted by individual SHRs after pressing the LL-lever (Mdn =  $0.01x$ , range from  $-0.00$  to  $0.09$ ). Correlations between licks emitted by individual SHRs after pressing the SS-lever and delay components (Mdn =  $.814$ , range from  $-.573$  to  $.973$ ), are like ( $W = 20$ ,  $p = .834$ ) correlations corresponding to licks emitted by individual LEWs (Mdn =  $.627$ , range from  $.054$  to  $.914$ ). Similarly, correlations between licks emitted by individual SHRs after pressing the LL-lever and delay components (Mdn =  $.773$ , range from  $-.788$  to  $.963$ ), are like ( $W = 20$ ,  $p = .834$ ) correlations corresponding to licks emitted by individual LEWs (Mdn =  $.624$ , range from  $-.648$  to  $.870$ ).

The bottom row of graphs shows licks emitted by SHRs and LEWs in the terminal link during delays to LLF greater than  $0.1$  s. The left graph shows licks emitted by the group of SHRs (Mdn = 136, range from 3 to 1740) similar ( $W = 10$ ,  $p = .589$ ) to licks emitted by the group of LEWs (Mdn = 117, range from 2 to 2088). Fits to licks emitted by SHRs ( $R^2 = .628$ ) and LEWs ( $R^2 = .723$ ) show positive correlations between licks emitted in the terminal link and delays to LLF ( $r = .849$  and  $.890$ , respectively). The slope of the line fitting licks emitted by the group of LEWs ( $0.13x$ ) is steeper than the slope of the line fitting licks emitted by the group of SHRs ( $0.09x$ ), indicating that licks emitted by the LEWs increased faster with increasing delay to LLF than licks emitted by the SHRs. Licks emitted by the individual SHRs (Mdn = 106, range from 0 to 4669) are similar ( $W = 481$ ,  $p = .052$ ) to licks emitted by the individual LEWs (Mdn = 11, range from 0 to 10725). Linear fits to licks emitted by the individual SHRs generated  $R^2$  ranging from  $.493$  to  $.835$  (Mdn =  $.613$ ) and linear fits to licks emitted by the individual LEWs  $R^2$  ranging from  $.590$  to  $.887$  (Mdn =  $.769$ ). Slopes of lines fitting licks emitted by the individual SHRs (Mdn =  $.13x$ , range from  $.10$  to  $.16$ ), were like ( $W = 21$ ,  $p = .726$ ) slopes of lines fitting licks emitted by the individual LEWs (Mdn =  $.13x$ , range from  $.05$  to  $.18$ ). Correlations between licks emitted by individual SHRs and delays to LLF (Mdn =  $.842$ , range from  $.505$  to  $9.36$ ) were like ( $W = 6$ ,  $p = .080$ ) correlations corresponding to licks emitted by individual LEWs (Mdn =  $.909$ , range from  $.832$  to  $9.57$ ).



**Figure 6.** Licks to the spout of the bottle in condition (B<sub>w</sub>). The top row of graphs shows licks in blackout periods separating delay components plotted against blocks of sessions. The second row of graphs shows licks before starting the initial link, and the third row of graphs shows licks in the initial link after pressing the SS- and LL-lever plotted against delay components. The bottom row of graphs shows licks in the terminal link plotted against delays to the LLF greater than 0.1-s. Unfilled symbols stand for licks emitted by the individuals and filled symbols are the means of licks computed for the group of SHR (circles) and the group of LEW (squares). The lines are the best fits of linear regression. Resulting parameters and linear equations appear on each graph.

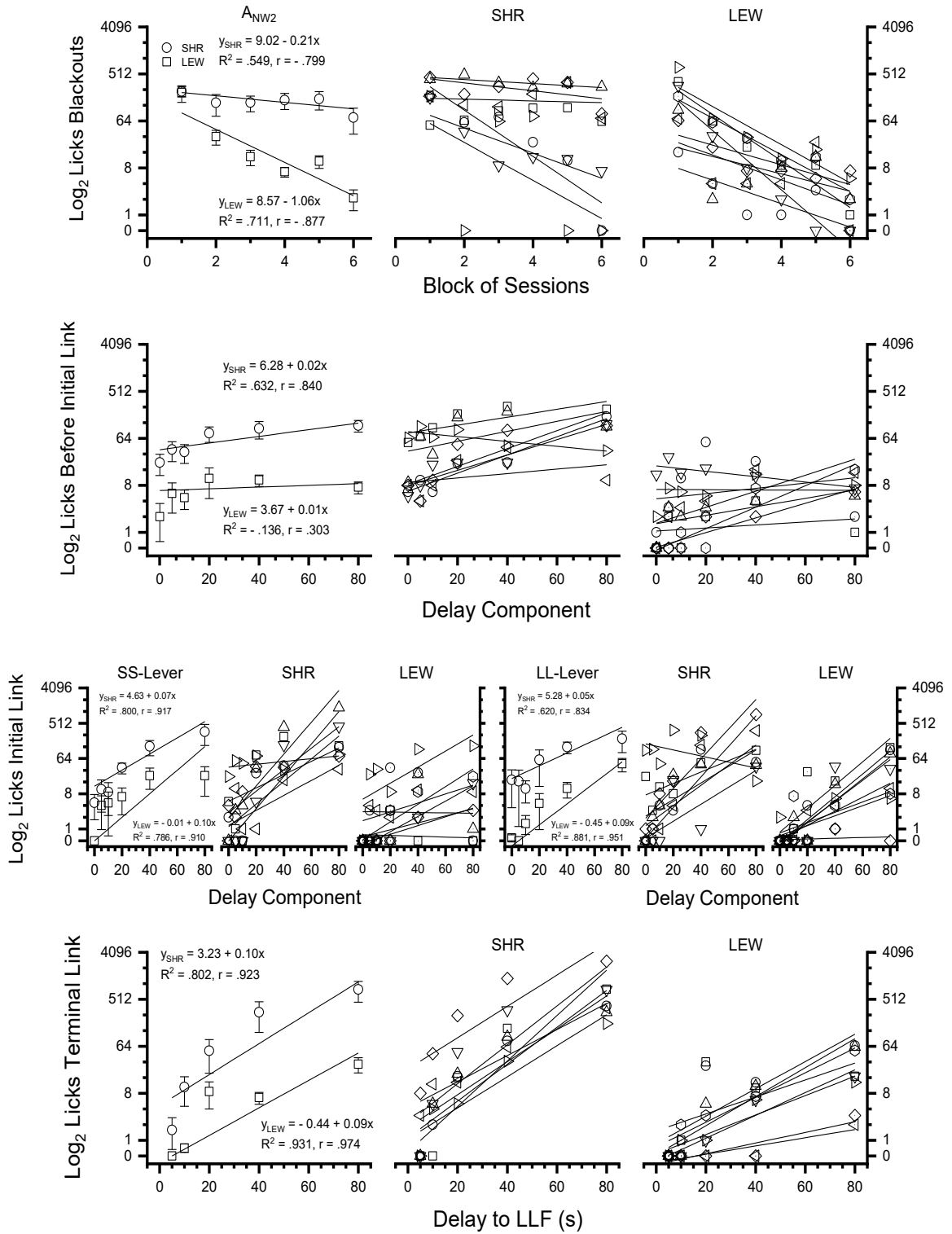
Figure 7 shows licks emitted by SHRs and LEWs in the last no water condition ( $A_{NW2}$ ) where the bottle with the water was removed from the chamber, leaving the spout of the bottle attached to the photo-operandum buffer recording licks. Licks emitted by SHRs and LEWs decreased in blackouts across blocks of sessions (top graphs). The licks emitted by the group of SHRs (Mdn = 152, range from 74 to 236) are greater ( $W = 21, p = .018$ ) than the licks emitted by the group of LEWs (Mdn = 12, range from 2 to 224). Linear fits to licks emitted by SHRs ( $R^2 = .549$ ) and LEWs ( $R^2 = .711$ ) show negative correlations between licks in blackouts and blocks of sessions ( $r = -.799$  and  $-.877$ , respectively). The slope of the line fitting licks emitted by the group of LEWs ( $-1.06x$ ) is steeper than the slope of the line fitting licks emitted by the group of SHRs ( $-0.21x$ ), indicating that licks emitted by LEWs decreased faster with increasing blocks of sessions than licks emitted by SHRs. Licks emitted by individual SHRs (Mdn = 106, range from 0 to 492) are greater ( $W = 736, p < .0001$ ) than licks emitted by individual LEWs (Mdn = 7.5, range from 0 to 683). Fits to licks emitted by individual SHRs generated  $R^2$  ranging from  $-.230$  to  $.797$  (Mdn =  $.121$ ) and fits to licks emitted by the individual LEWs  $R^2$  ranging from  $.041$  to  $.933$  (Mdn =  $.632$ ). Slopes of lines fitting licks emitted by individual SHRs (Mdn =  $-0.25x$ , range from  $-1.48$  to  $0.11$ ) are equivalent ( $W = 24, p = .108$ ) to slopes of lines fitting licks emitted by individual LEWs (Mdn =  $-0.79x$ , range from  $-1.90$  to  $-0.55$ ). Negative correlations between licks emitted by individual SHRs and blocks of sessions (Mdn =  $-.545$ , range from  $-.915$  to  $.423$ ) are like ( $W = 23, p = .151$ ) negative correlations between licks emitted by individual LEWs and blocks of sessions (Mdn =  $-.840$ , range from  $-.973$  to  $-.482$ ).

The second row of graphs shows licks emitted by SHRs and LEWs before starting the initial link increasing across delay components. Licks emitted by the group of SHRs (Mdn = 59, range from 22 to 112) are greater ( $W = 21, p = .018$ ) than licks emitted by the group of LEWs (Mdn = 7, range from 2 to 11). Lines fitting licks emitted by SHRs ( $R^2 = .632$ ) and LEWs ( $R^2 = -.136$ ), show positive correlations between licks emitted before starting the initial link and delay components ( $r = .840$  and  $.303$ , respectively). The slope of the line fitting licks emitted by SHRs ( $0.02x$ ) is comparable to the slope of the line fitting licks emitted by LEWs ( $0.01x$ ) showing licks increasing across delay components. Licks emitted by individual SHRs before starting the initial link (Mdn = 40, range from 4 to 260) are greater ( $W = 840, p < .0001$ ) than licks emitted by the individual LEWs (Mdn = 4, range from 0 to 54). Lines fitting licks emitted by individual SHRs before starting the initial link generated  $R^2$  ranging from  $-.105$  to  $.910$  (Mdn =  $.537$ ), and lines fitting licks emitted by individual LEWs generated  $R^2$  ranging from  $-.250$  to  $.841$  (Mdn =  $.330$ ). Slopes of lines fitting licks emitted by individual SHRs (Mdn =  $0.03x$ , range from  $-0.02$  to  $0.06$ ) are similar ( $W = 19, p = .447$ ) to slopes of lines fitting licks emitted by individual LEWs (Mdn =  $0.02x$ , range from  $-0.02$  to  $0.05$ ). Correlations between licks emitted by individual SHRs and delay components (Mdn =  $.789$ , range from  $-.793$  to  $.963$ ) are comparable ( $W = 16, p = .800$ ) to correlations computed with licks emitted by individual LEWs (Mdn =  $.562$ , range from  $-.784$  to  $.934$ ).

The third row of graphs shows licks emitted by SHRs and LEWs in the initial link after pressing the SS-lever (left graphs) and LL-lever (right graphs) plotted against delay components. Licks emitted by the group of SHRs after pressing the SS-lever (Mdn = 24, range from 5 to 306) are greater ( $W = 21, p = .015$ ) than licks emitted by the group of LEWs (Mdn = 6, range from 0 to 23). Linear fits to licks emitted by the SHRs ( $R^2 = .800$ ) and LEWs ( $R^2 = .786$ ) show positive correlations between licks emitted after pressing the SS-lever and the delay components ( $r = .917$  and  $.910$ ). The slope of the line fitting licks emitted by the group of LEWs ( $0.10x$ ) is steeper than the slope of the line fitting licks emitted by the group of SHRs ( $0.07x$ ), showing licks emitted by group of LEWs after pressing the SS lever increasing faster across delay components than licks emitted by the group of SHRs. Licks emitted by individual SHRs after pressing the SS-lever (Mdn = 20, range 0 to 1277) are greater ( $W = 551, p < .0001$ ) than licks emitted by individual LEWs (Mdn = 0, range 0 to 135). Linear fits to licks emitted by SHRs after pressing the SS-lever generated  $R^2$  ranging from  $.063$  to  $.854$  (Mdn =  $.588$ ) and linear fits to licks emitted by the LEWs  $R^2$  ranging from  $-.250$  to  $.939$  (Mdn =  $.351$ ). Slopes of lines fitting licks emitted by individual SHRs (Mdn =  $0.09x$ , range  $0.01$  to  $0.14$ ) are like ( $W = 25, p = .076$ ) slopes of lines fitting licks emitted by individual LEWs (Mdn =  $0.04x$ , range  $-0.01$  to  $0.07$ ). Correlations between licks emitted by individual SHRs after pressing the SS-lever and delay components (Mdn =  $.819$ , range  $.501$  to  $.940$ ) are comparable ( $W = 19, p = .447$ ) to correlations between licks emitted by individual LEWs and delay components (Mdn =  $.693$ , range  $-.953$  to  $.975$ ).

Licks emitted by the group of SHRs after pressing the LL-lever (Mdn = 39, range from 11 to 205) are greater ( $W = 21$ ,  $p = .018$ ) than licks emitted by the group of LEWs (Mdn = 3, range from 0 to 47). Linear fits to licks emitted by SHRs ( $R^2 = .620$ ) and LEWs ( $R^2 = .881$ ) show positive correlations between licks emitted in the initial link after pressing the LL lever and delay components ( $r = .834$  and  $.951$ , respectively). Licks emitted by LEWs increased faster across delay components than licks emitted by SHRs, the slope of the line fitting licks emitted by LEWs ( $0.09x$ ) is steeper than the slope of the line fitting licks emitted by SHRs ( $0.05x$ ). Licks emitted by individual SHRs after pressing the LL-lever (Mdn = 15, range 0 to 849) are greater ( $W = 519$ ,  $p < .0001$ ) than licks emitted by individual LEWs (Mdn = 0, range 0 to 121). Fits to licks emitted by individual SHRs generated  $R^2$  ranging from  $.050$  to  $.856$  (Mdn =  $.538$ ) and fits to licks emitted by the individual LEWs  $R^2$  ranging from  $-.183$  to  $.847$  (Mdn =  $.717$ ). Slopes of lines fitting licks emitted by individual SHRs after pressing the LL lever (Mdn =  $0.07x$ , range  $-0.03$  to  $0.13$ ) are like ( $W = 13$ ,  $p = .932$ ) slopes of lines fitting licks emitted by the individual LEWs (Mdn =  $0.09x$ , range  $0.00$  to  $0.10$ ). Correlations between licks emitted by individual SHRs after pressing the LL-lever and delay components (Mdn =  $.834$ , range  $-.490$  to  $.974$ ) are like ( $W = 10$ ,  $p = .554$ ) correlations corresponding to licks emitted by individual LEWs (Mdn =  $.880$ , range  $.231$  to  $.937$ ).

The bottom row of graphs shows licks emitted by SHRs and LEWs in the terminal link during delays to LLF greater than  $0.1$  s. The left graph shows licks emitted by the group of SHRs increasing from 2 to 791 (Mdn = 53) greater ( $W = 15$ ,  $p = .030$ ) than licks emitted by the group of LEWs increasing from 0 to 29 (Mdn = 7). Fits to licks emitted by SHRs and LEWs ( $R^2 = .802$  and  $.931$ ) show positive correlations between licks emitted in the terminal link and delays to LLF ( $r = .923$  and  $.974$ , respectively). The slope of the line fitting licks emitted by the group of SHRs ( $0.10x$ ) is like the slope of the line fitting licks emitted by the group of LEWs ( $0.09x$ ), showing licks increasing with the increasing delay to LLF. Licks emitted by individual SHRs (Mdn = 19, range 0 to 2767) are greater ( $W = 442$ ,  $p < .0001$ ) than licks emitted by individual LEWs (Mdn = 1, range 0 to 66). Fits to licks emitted by individual SHRs generated  $R^2$  ranging from  $.617$  to  $.919$  (Mdn =  $.805$ ) and fits to licks emitted by individual LEWs  $R^2$  ranging from  $.190$  to  $.915$  (Mdn =  $.742$ ). Slopes of lines fitting licks emitted by individual SHRs (Mdn =  $0.10x$ , range from  $0.08$  to  $.15$ ) are steeper ( $W = 28$ ,  $p = .011$ ) than slopes of lines fitting licks emitted by individual LEWs (Mdn =  $0.06x$ , range from  $0.03$  to  $.09$ ). Yet, positive correlations between licks emitted by individual SHRs and delays to LLF (Mdn =  $.924$ , range  $.882$  to  $.969$ ) are like ( $W = 17$ ,  $p = .673$ ) positive correlations corresponding to licks emitted by individual LEWs (Mdn =  $.898$ , range  $.627$  to  $.967$ ).



**Figure 7.** Licks to the spout of the bottle in the last no-water condition (ANW2). Other details as in Fig. 6.

## Discussion

The present study extended the generality of findings showing that the performance of the SHR on concurrent-chains procedures varying the delay to the LLF within the session, is like the performance of the LEW (Aparicio, 2023). Both strains of rats choose impulsively between the SSF and LLF showing proportions of LL choice decreasing as a function of the increasing delay to LLF (Aparicio et al., 2015; 2019; 2022). Discounting functions produced by SHR and LEW indicated low discounting rates after sixty days of training in condition  $A_{NW1}$ , but the LEW produced discounting rates higher than those produced by the SHR, confirming that the LEW chooses more impulsively at the beginning of training than the SHR (Aparicio et al., 2022). As training in condition  $A_{NW1}$  advanced both strains of rats made more impulsive choices, producing discounting functions showing discounting rates increasing with increasing number of sessions. At the end of condition  $A_{NW1}$  the SHR produced discounting functions indicating more impulsive choices and greater discounting rates than those produced by LEW, replicating previous findings (Aparicio et al., 2022; Aparicio, 2023). The present results showing impulsive choices made by SHR and LEW increasing as a function of extended training in the choice situation (Aparicio et al., 2013; 2015; 2019), support the conception that impulsive behavior is adaptive to organisms (Fawcett, McNamara, and Houston, 2012), impulsivity is not a static trait of behavior entirely governed by genetic and neurochemical factors (Aparicio et al., 2019; 2022).

Eq. 1 fitted the proportions of LL choice produced by SHR and LEW well (Table 1), with resulting parameters indicating that both sensitivity of choice to magnitude of LLF ( $A$ ) and discounting rate ( $k$ ) increased with increasing sessions of training in condition  $A_{NW1}$  supporting the conclusion that impulsive choice in SHR and LEW rats increases with lengthy training in the choice situation regardless of their neurochemical, genetic, and current physiological conditions at the beginning of training (Aparicio, 2023; Aparicio et al., 2019; 2022). Overall, the results of the present study are consistent with those showing that Mazur's (1987) hyperbolic decay model appropriately describes delay discounting data produced by humans (Meyerson and Green, 1995; Rachlin et al, 1991) and non-human animals (Aparicio, 2015; 2023; Aparicio et al., 2013; 2015; 2019; 2022); Farrar et al., 2003; Green et al, 2007; Mazur, 2012; Stein et al, 2012).

A bottle with water was available in condition  $B_W$  exploring the possibility that allowing the rats to engage in another activity (drink water) during the delay to obtain the LLF will reduce their impulsive choices (Grosch and Neuringer, 1981). The SHR and LEW produced discounting functions comparable to those produced in condition  $A_{NW1}$ , the SHR's impulsive choices did not decrease and the LEW's impulsive choices maintained an increasing trend producing discounting functions like those produced by the SHR, challenging Grosch's and Neuringer (1981) prediction that impulsivity will decrease if another activity (drinking water) is available for the organism to engage during the delay to obtain the LLF. Moreover, the discounting rates estimated for the impulsive choices made by SHR and LEW in blocks of sessions 1-4 of condition  $B_W$  were like the discounting rates estimated for their impulsive choices in blocks of sessions 8-10 of condition  $A_{NW1}$ , challenging the results showing impulsive choice increasing in rats developing polydipsia (Íbias and Pellón, 2011) and ruling out a positive correlation between polydipsia and impulsivity (Ramos et al., 2019). Impulsive choices made by the LEW in condition  $B_W$  were comparable to impulsive choices made by the SHR (Fig. 2). However, the SHR's impulsive choices reached an asymptotic level in condition  $A_{NW1}$ , contrasting with the LEW's impulsive choices requiring all sessions of condition  $A_{NW1}$  and sixty more sessions of condition  $B_W$  to reach an asymptotic level and produce discounting rates like those produced by the SHR.

The bottle with water was removed from the choice situation in condition  $A_{NW2}$ , leaving the spout of the bottle attached to the hopper recording licks to it during the session. The SHR and LEW produced discounting functions (Fig. 3) like those produced in condition  $B_W$  (Fig. 2). Eq. 1 fitted the proportions of LL choice produced by the SHR and LEW well (Table 3). The discounting functions produced by the SHR were indistinguishable from those produced by the LEW, with data points corresponding to proportions of LL choice and fitting lines overlapping to one another. Estimates

of sensitivity of choice to the magnitude of the LLF ( $A$ ) and discounting rate ( $k$ ) indicated that the impulsive choices made by the SHR were like the impulsive choices made by the LEW (Table 3). Moreover, the impulsive choices made by the SHR and LEW in conditions  $B_W$  and  $A_{NW2}$  showed higher sensitivity of choice to the magnitude of the LLF ( $A$ ) and greater discounting rate ( $k$ ) than in condition  $A_{NW1}$ , indicating that SHR and LEW rats do not choose between the SSF and LLF less impulsively when drinking water ( $B_W$ ) and licking the spout of a bottle ( $A_{NW2}$ ) are activities available to engage during the delay to the LLF (Aparicio, 2023). Lastly, the rats' sensitivity of choice to the magnitude of the LLF increased in conditions  $B_W$  and  $A_{NW2}$ , demonstrating that when parameter  $A$  is not assumed to be 1.0 LL choice at the  $y$ -intercept,  $A$  increases with the rats' experience in the choice situation (Aparicio et al., 2022).

### 3.2. Polydipsia

Both strains of rats developed polydipsia in condition  $B_W$  (Fig. 5), but the SHR consumed more milliliters of water in each session than the LEW. The analysis of the milliliters of water consumed by the SHR and LEW showed the acquisition of polydipsia (blocks of sessions 1 to 4), the maintenance of polydipsia (blocks of sessions 5 to 7), and a following reduction of polydipsia (blocks of sessions 8 to 10). A positive correlation between milliliters of water consumed by the rats and sessions of blocks 1 to 4 characterized the acquisition of polydipsia (Fig. 5), with the LEW's consumption of water increasing faster across sessions than the SHR's consumption of water. The milliliters of water consumed by the SHR and LEW changed slightly in sessions of blocks 5 to 7 suggesting the maintenance of polydipsia, with the milliliters of water consumed by the SHR showing a negative correlation with the sessions and the milliliters of water consumed by the LEW a positive correlation. A reduction in polydipsia occurred in the sessions of blocks 8 to 10, both strains of rats developed a decreasing trend in the milliliters of water consumed, but the SHR consumed more milliliters of water than the LEW suggesting more impulsive action in the SHR (Winstanley et al., 2006).

The acquisition of polydipsia suggests that it was induced by food (SSF and LLF) acting as a phylogenetically important event (Baum, 2021). Polydipsia was maintained by the rats until the behavior of drinking water competed with the behavior of pressing the levers to produce the SSF and LLF, causing polydipsia to decrease. The SHR and LEW emitted the highest numbers of licks to the spout of the bottle during the blackouts separating the delay components (Fig. 6), because the blackouts were regular intervals (1-min) separating six delay components delivering food (SSF and LLF) and regular intervals between food deliveries generate schedule-induced polydipsia (Falk, 1961), or adjunctive behavior (Falk, 1971). The licks emitted by the SHR and LEW before starting the initial link were parts of the bursts of licks occurring at the end of each blackout running over the time where pressing the back lever started the initial link. Both strains of rats emitted the highest numbers of licks during blackouts and times before starting the initial link, because licking the spout of the bottle did not compete with the behavior of pressing the levers during blackouts and times before starting the initial link. These findings support the laws of allocation, induction, and covariance (Baum, 2018a; 2018b). Licking was induced by food (SSF and LLF), licking was allocated in blackouts and times before starting the initial link, and licking covaried with lever-pressing in the initial link and terminal link. The SHR emitted more licks after pressing the SS-lever than the LEW, but the LEW emitted more licks after pressing the LL-lever than the SHR, suggesting that the LEW's discrimination between the LL-lever producing the LLF with delays allowing licks and the SS-lever producing the SSF with a 0.1-s delay restricting licks, was more efficient than the SHR's discrimination due to poor sustained attention (Diana, 2002) and learning deficits in the SHR (Meneses & Hong, 1998). Yet, the licks emitted by the SHR and LEW increased in the terminal link as a function of the increasing delay to get the LLF, but the SHR emitted more licks than the LEW, indicating more hyperactivity in the SHR (Knardahl and Sagvolden, 1979; Sagvolden et al., 1992). Nonetheless, both strains of rats emitted more licks to the spout of the bottle during the 20- and 40-seconds delays to LLF than during the 80-s delay to the LLF due to a feedback loop between pressing the LL-lever and producing the LLF (Baum, 2021).

Condition  $A_{NW2}$  explored the following possibilities. If water was necessary to maintain the behavior of licking the spout of the bottle in condition  $B_W$ , then the absence of the water in condition  $A_{NW2}$  might cause the extinction of the licking behavior. But if water is not a necessary condition to maintain licking, then licking is a food related behavior, and it should be induced by food functioning as a phylogenetically important event (Baum, 2021). Both strains of rats licked the spout of the bottle in condition  $A_{NW2}$ , but the SHR licked it more times than the LEW. The licks emitted by the SHR and LEW showed a tendency to decrease in the blackouts, but their licks did not progress to complete extinction, with the licks emitted by the SHR showing more resistance to extinction than the licks emitted by the LEW (Fig. 7). Also, the licks emitted by the SHR and LEW before starting the initial link, their licks in the initial link after pressing the SS-lever and LL-lever, and their licks in the terminal link did not indicate complete extinction with the SHR emitting more licks to the spout of the bottle than the LEW. These findings illustrate the laws of induction, allocation, and covariance (Baum, 2018a; 2018b) showing that the behavior of licking the spout of the bottle was induced by food, and it was allocated in blackouts and times before starting the initial link where it covaried with lever-pressing. But licking the spout of the bottle in the initial and terminal links competed with the behavior of pressing the SS-lever and LL-lever due to a feedback loop between pressing the levers and producing the SSF and LLF food (Baum, 2021).

### Conclusions

Impulsive choice and polydipsia were analyzed in the SHR and LEW two rodent models of ADHD. The performance of SHR on concurrent-chains procedures varying the delay to the LLF within the session was like the performance of LEW, extending the generality of findings suggesting that the LEW is a suitable control to the SHR (Aparicio, 2023; Aparicio et al., 2022). Both strains of rats produced proportions of LL choice decreasing as a function of the increasing delay to the LLF, indicating that impulsive choice in SHR and LEW rats increases with extended training in the choice situation (Aparicio et al., 2013; 2015; 2019). The discounting functions produced by the SHR and LEW showed estimates of discounting rate ( $k$ ) increasing as a function of the increasing sessions of condition  $A_{NW1}$ , supporting the notion that impulsivity is adaptive to the organism (Fawcett, McNamara, and Houston, 2012). Sensitivity of choice to the magnitude of the LLF ( $A$ ) increased with the rats' experience in the choice situation indicating that when  $A$  is free to vary, it is not assumed to be 1.0 LL choice at  $y$ -intercept,  $A$  increases systematically (Aparicio et al., 2015; 2019).

When a bottle with tap water was available to drink in the choice situation (condition  $B_W$ ), the impulsive choices made by the SHR did not decrease and the impulsive choices made by LEW maintained the increasing trend developed in condition  $A_{NW1}$  producing discounting rates comparable to those produced by the SHR. These results questioned the prediction that impulsive choice will decrease when another activity (e.g., drinking water) is available in the choice situation for the organism to engage during the delay to the LLF (Grosch and Neuringer, 1981). The polydipsia developed by the SHR and LEW was induced by food acting as a PIE (Baum, 2021). The SHR and LEW emitted the highest number of licks to the spout of the bottle during blackouts separating six delays to LLF, because regular intervals between food generate schedule-induced polydipsia (Falk, 1961), or adjunctive behavior (Falk, 1971). The behavior of licking the spout of the bottle during the initial and terminal links tended to decrease with respect to licking during blackouts and intervals before starting the initial link. These findings support the laws of allocation, induction, and covariance (Baum, 2018a; 2018b) showing that the SHR and LEW allocated the behaviors of licking and pressing, both behaviors were induced by food (SSF and LLF), and the behavior of pressing the levers competed with that of licking the spout of the bottle due to a feedback loop where food induces pressing and that activity produces the food (Baum, 2021). An analysis of milliliters of water consumed by the rats revealed that the SHR consumed more water than the LEW, suggesting motor impulsivity in the SHR (Winstanley et al., 2006). Both strains of rats licked the spout of the bottle in condition  $A_{NW2}$  showing that the water was not necessary to maintain licking, licking was induced by food acting as PIE (Baum, 2018a; 2018b). The licks emitted by the SHR and LEW decreased in condition  $A_{NW2}$ , but their licks did not show complete extinction; particularly, the SHR's licks showed strong resistance to extinction. Further research looking for a relation between polydipsia and impulsivity might find the present study useful to identify factors determining impulsive choice in

SHR and LEW rats. It is concluded that impulsive choice in SHR and LEW rats increases with extended experience in the choice situation regardless of their genetic, neurochemical, and physiological conditions at the beginning of the study (Aparicio et al., 2013; 2015; 2019). The cumulative body of evidence suggests that the LEW is a proper control to the SHR (Aparicio et al., 2022).

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