

Assessment of the ‘timing’ function of schedule-induced behavior on fixed-interval performance

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We have no conflict of interest to disclose.

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Abstract

It has been suggested that schedule-induced behaviors allow organisms to adapt better to temporal regularities of the environment. The main goal of the present study was to observe the effect of schedule-induced drinking (SID) on the performance in fixed-interval (FI) schedules. Rats were exposed to a FI 15, 30 or 60 s food reinforcement schedule, and only half of them had access to water in the experimental chamber. Rats with access to water developed SID, which occurred in the first part of the interval, regardless of the FI value, and was followed by an increase in lever pressing rate. There were no substantial differences in the quantitative measures of timing between groups that had or did not have access to water, except for the rats in the FI 15 s group with access to water, that showed longer post-reinforcement pauses, possibly due to competition between SID and lever pressing. SID did not manifest the scalar property, contrary to lever pressing, but it is proposed that behaviors are displayed serially until the last behavior before the target operant response becomes a discriminative stimulus for that behavior. It is not assumed that the purpose of schedule-induced behaviors is to aid timing, but the development of behavioral patterns might determine the performance of organisms on temporal tasks. Additionally, in some cases competition between responses might exert more control on when the operant behavior occurs than timing. Timing seems to consist in the temporal organization of available behaviors that leads to a specific behavior occurring at a specified time, a single characteristic that typically had come to indicate 'accurate timing'.

Keywords: schedule-induced behaviors, timing, induction, reinforcement, behavioral patterns

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Schedule-induced behaviors (previously known as adjunctive) are those that develop at an excessive rate during the inter-reinforcement interval of an intermittent reinforcement schedule without having an explicit arranged contingency between its occurrence and reinforcer delivery (Pellón et al., 2020). Although the development of schedule-induced behaviors has been widely documented (for some revisions, see, Falk, 1971; López-Tolsa, 2019; Pellón, 1990; Roper, 1981), there is still no agreement as to *why* they occur and *how* they are maintained. Albeit they were initially considered as a type of behavior different from operant behavior, currently there are two prevailing hypotheses about the origin and maintenance of schedule-induced behaviors that explain their development in the same terms than the development of the traditionally considered operants, either by reinforcement (Killeen & Pellón, 2013) or induction (Baum, 2012).

After several years of investigating schedule-induced behaviors, Pellón and colleagues (Ardoy & Pellón, 2004; Gutiérrez-Ferre & Pellón, 2019; Íbias & Pellón, 2011; Pellón & Blackman, 1987; Pellón & Castilla, 2000; Pellón & Pérez-Padilla, 2013; Ramos et al., 2019) concluded that they are operants, either individually maintained by delayed reinforcement (Killeen & Pellón, 2013; Pellón & Killeen, 2015) or as part of a behavioral pattern that is reinforced as a whole and is repeated on every inter-reinforcement interval (Ruiz et al., 2016; Segal et al., 1965), a view that is also consistent with Skinner’s proposal on contiguity, instead of contingency, as necessary for the establishment of an operant behavior (Skinner, 1948).

From an apparently opposite view, Baum (2012, 2018) stated that all behaviors are induced by means of correlation with phylogenetically important events (PIEs; i.e. reinforcers). Baum

compares the process of induction with the presentation of discriminative stimuli, in the sense that, after a few pairings of a behavior with a PIE, the rate of occurrence of that specific behavior increases in the presence of that specific PIE (see also, Cowie et al., 2011, 2017, for a similar interpretation of the discriminative function of reinforcers).

Even though the operant *vs.* induced mechanisms seem to be opposite explanations at first sight, both views have some common assumptions: a) contingency is not considered to be a cause-effect relationship, but the contiguous occurrence of a behavior and a reinforcer/PIE (Baum, 2012; Killeen & Pellón, 2013); b) immediate reinforcement is not necessary for behavior to be acquired (Baum, 2015; Killeen & Pellón, 2013); c) repeated presentations of reinforcement/PIEs increase the occurrence of some behaviors, while decreasing the occurrence of others (i.e. behaviors compete with each other) (Baum, 2012; Baum & Grace, 2020; Killeen, 1975; Pellón & Killeen, 2015); and, d) they do not distinguish between types of behaviors (e.g. operant *vs.* adjunctive) (Baum & Grace, 2020; Killeen & Pellón, 2013). These views are also consistent with Timberlake's proposal that schedule-induced behaviors are part of species-specific behavioral systems that are elicited with the delivery of the reinforcement (Timberlake & Lucas, 1985; see a recent treatment in Killeen, 2014).

Moreover, even if reinforcement and induction were two different processes, it is quite possible that they both have a role in the development and maintenance of behavior. Álvarez et al. (2016) exposed rats to a fixed time (FT) 90 s schedule of food delivery and established a 100, 50 and 0 % contingency between licking to a water-bottle spout and shortening the inter-food interval. They found that rats with 100 % contingency developed licking faster and drank more than subjects in the other two groups. Their results showed that drinking can be both schedule induced and strengthened by its consequences.

Behaviors interact and compete during inter-reinforcement intervals (Baum, 2012; Killeen, 1975; Pellón & Killeen, 2015; Segal et al., 1965), and their distributions depend on the reinforcement schedule (Roper, 1978; Rosellini & Burdette, 1980), the animal species used (Millenson et al., 1977), and the complexity and size of the environment in which the organisms are tested (Skuban & Richardson, 1975; Staddon & Ayres, 1975). Nevertheless, once a specific pattern of behaviors is developed, it tends to occur in a semi-invariant way (i.e. in the same order, for similar periods of time) during most of the inter-reinforcement intervals if all the environmental conditions remain constant (Baum & Grace, 2020; Cleaveland et al., 2003; Lawler & Cohen, 1992; Ruiz et al., 2016; Segal & Holloway, 1963; Staddon & Ayres, 1975; Staddon & Simmelhag, 1971).

Based on the development of those behavioral patterns, Killeen and Fetterman (1988) proposed the behavioral theory of timing (BeT), which states that timing ability depends on a progression through chains of classes of schedule-induced behaviors that function as a discriminative stimulus of the temporal moment in which they usually occur (like a behavioral clock). Furthermore, Fetterman et al. (1998) argued that ‘timing’ is the ability of an organism to use natural sequences of stimuli and/or responses in the environment and discriminating their own behavior to perform appropriately in a temporal-controlled situation.

Machado (1997; Machado & Keen, 1999; Machado et al., 2009) further elaborated on the BeT model to propose a theory that could mathematically explain and predict the learning process in a variety of timing procedures (the learning-to-time, LeT, model). According to LeT, a series of behavioral states are activated throughout conditioning trials, and each state is coupled with the operant response to a different degree (higher degrees during reinforcement, lower degrees during extinction) that changes in real time. The states that occur in proximity to the

time of reinforcement have a stronger coupling, and therefore exert more control over the operant response, becoming a discriminative stimulus for the operant behavior (for a complete explanation of the model, see Machado, 1997; Machado et al., 2009; Vasconcelos et al., 2017). The velocity of the activation across states varies with the overall reinforcement rate, thus implying that the behavioral states distribute along the inter-reinforcement interval showing the scalar property, in the same way as operant behaviors do (Vasconcelos et al., 2017). The behavioral states are all other behaviors occurring during the inter-reinforcement interval (i.e. schedule-induced behaviors), that underlie the temporal organization of behavior, but the precise relation between them and the operant response has often been assumed or inferred, rather than experimentally tested (Machado et al., 2009).

Some attempts have been made to empirically study the effect of schedule-induced behaviors on temporal tasks. Segal and Holloway (1963) and Laties et al. (1969) observed the effect of schedule-induced drinking on the performance under differential reinforcement of low rates (DRL) schedules, and they observed that rats developed a pattern of behavior that included schedule-induced behaviors and operant lever-pressing, and that, in both studies, larger amounts of schedule-induced behaviors led to larger amounts of earned reinforcers. Also, if the schedule-induced behavior was prevented, interrupted, or absent, the performance on the DRL schedule was less accurate (i.e. rats pressed the lever earlier in the interval, so they did not obtain as many reinforcers). Additionally, Bruner and Revusky (1961) studied the performance of high school students under a DRL schedule. They observed that the participants developed systematic patterns of responses to collateral keys (i.e. schedule-induced responses) before pressing the reinforcing key. In post-experimental interviews, the participants revealed that they thought they had to do the pattern of responses in order to obtain the reinforcer.

Lejeune et al. (1998) directly evaluated the role of schedule-induced behaviors in a temporal task and concluded that they do not mediate timed responses because they do not occur in the same amount on *every* interval, even though they found evidence of consistent patterns that included schedule-induced and target behaviors. On the other hand, Machado and Keen (1999) exposed pigeons to a temporal discrimination task and observed that each subject developed a behavioral pattern that was consistent across trials and that correlated with their choices in a generalization test. They concluded that behaviors occurring in the inter-reinforcement intervals *are* the behavioral clock, not just a representation or expression of an internal clock. Furthermore, Machado and Keen (2003) recorded the location of pigeons in a long box, and observed how it changed during the interval, first remaining in the side where a short stimulus was followed by reinforcement, and then moving to the other side in which a reinforcement followed a long stimulus. Cleaveland et al. (2003) found similar results using a delayed matching to sample procedure. In that study, budgerigars developed regular patterns of behavior during the delays, and they tended to choose depending on the behavior they were performing, independently of the comparison stimulus presented at the beginning of the interval.

The aforementioned studies suggest that behavioral patterns developed during inter-reinforcement intervals may have an impact on the performance of organisms in time-base tasks, nevertheless, that impact has normally been inferred or *accidentally* observed, rather than put into test. In order to observe the effect of developing a specific schedule-induced behavior (e.g., drinking), which would increase the availability of behaviors to be integrated into the pattern compared to a standard procedure, the performance of such organisms should be compared to the performance of organisms under similar conditions, but without the opportunity to develop the specific schedule-induced behavior.

The goal of the present study was to evaluate the effect of developing schedule-induced drinking (SID) (the best characterized schedule-induced behavior) on the performance of rats in fixed-interval (FI) schedules. FI schedules have been widely used to study the adjustment of organisms to temporal regularities (Guilhardi & Church, 2004; Lejeune and Wearden, 1991; López, 2012). Additionally, it is a schedule under which schedule-induced drinking develops easily and consistently (Falk, 1966; Flores & Pellón, 1995, 1997; Flory, 1971; Ruiz et al., 2016). FI schedules produce a behavioral pattern that consists on an initial low rate of operant responses followed by a high rate of responding (break-and-run), that looks like a positively accelerated curve (scallop) when average data are plotted (Baron & Leinenweber, 1994). Although the ‘ideal’ timing performance in a FI would consist in a single response just after the FI elapsed, that is rarely the case, so the accuracy of the performance on FI schedules can be measured in several ways, including response rate, time to *n*th response (e.g., post-reinforcement pause), time of transition (i.e. breakpoint), among others (Guilhardi & Church, 2004).

López and Menez (2005, 2012) reported that the acquisition of the FI scallop is facilitated when organisms have previous experience in other reinforcement schedules with temporal regularities, but not when they have experience on variable- or random-time schedules. Additionally, Sanabria et al. (2009) observed that when pigeons were responding on concurrent schedules (random-ratio/random-interval and fixed-interval with peak intervals) they would develop a pattern of responses that delayed the start time of responding to the peak-interval schedule, thus improving their timing performance. It is possible that schedule-induced drinking will become part of behavioral patterns that allow organisms to adapt better to temporal regularities of the environment, and that researchers interpreted those results as a ‘better’ performance in temporal tasks (Ruiz et al., 2016; Sanabria et al., 2009).

SID normally occurs during the first 10-20 s of each inter-food interval (Álvarez et al., 2016; Flores & Pellón, 1997), therefore the effect of its development on the accuracy of performance should be dependent on the FI length. Three values of FI were chosen: a short one in which SID would occur during most of the interval (FI 15 s); an intermediate one in which SID would occur only in about half of the interval (FI 30 s); and a long one in which SID would occur only in about the first quarter of the interval (FI 60 s).

Method

Subjects

Subjects were 44 experimentally naïve male Wistar rats that were 16 weeks old at the start of the experiment. Their weights were progressively reduced for 3 weeks before the experiment began and were maintained at about 80-85 % of their free-feeding weights with an initial average of 319 g (range: 233-451). They were housed individually in transparent Plexiglas cages measuring 18 x 32.5 x 20.5 cm in an environmentally-controlled room (22 °C and 55 % relative humidity) with a 12-hour light-dark cycle (lights on at 8:00 a.m.). Water was always available in the home cages. Animal care procedures were in accordance with the European Union Council Directive 2010/63, the Spanish Royal Decree 53/2013, and with the authorization of the Community of Madrid (ref. PROEX 077/18) and the bioethics committee of UNED.

Apparatus

Eight Letica LI-836 conditioning chambers (then customized by Cibertec SA, Madrid, Spain) measuring 29 x 24.5 x 35.5 cm were used. The front panel of each chamber was made of aluminum, the left wall of transparent Plexiglas and the remaining walls of black Plexiglas. The floor consisted on a 16-bar metal grid. In the center of the front wall at a height of 3.7 cm above the floor was located the food tray, at each side of the food tray there was a retractile lever, and

above each lever a 3-W round lamp. Only the left lever was used during this experiment, the right one stayed inactive and retracted. Forty-five mg sweet (sucrose-based, unflavored) food pellets were dispensed (Bio-Serv F0021, Frenchtown, NJ, USA) into the food tray by a Leticia Instruments dispenser. In the right wall, there was a 3.2 x 3.9 cm aperture, situated 20 cm from the front panel and 7 cm from the floor, through which subjects could reach the spout of a water bottle mounted on the exterior of the chamber. The water bottle could be removed if necessary. The spout was placed 2 cm towards the interior of the aperture to allow for licks rather than continuous drinking. Contact between the subject's tongue and the metal spout completed the electric circuit between the floor and the spout that allowed the recording of licks. Chambers were enclosed in a soundproofed housing equipped with a ventilation system and a small observation window in the left panel. A fan located in the soundproofed housing produced an ambient noise of approximately 60 dB in each chamber to mask any exterior noise. The houselight consisted on an indirect 25-W light mounted in the soundproofed housing. Chambers were controlled using a MED-PC application under a Windows environment.

Procedure

Subjects were divided into 6 groups, considering two variables: having or not water available (W vs. NW) in the conditioning chamber, and the value of the FI schedule of food reinforcement (Table 1). Groups W30 and NW30 had an $n = 6$ instead of 8 because 2 subjects in the W30 group did not develop SID, so they, and the subjects from the NW30 group that ran the experiment in the same chambers, were removed from the analyses.

Insert Table 1 about here

The experiment was conducted 6 days per week (Sunday to Friday), one session per day, and consisted of two phases: pre-training and training. Each session began with the illumination

of the houselight and the insertion of the left lever. All sessions were the same for all subjects of the same FI value groups, except that half of the rats had access to water in the conditioning chambers (W rats) and the other half did not (NW rats).

During pre-training, rats were exposed to an autoshaping-like procedure, in which a FT 30 s and a fixed-ratio 1 schedules were running simultaneously. Subjects received one food pellet every 30 s and also after every lever press. Each session in this phase ended when the subject pressed the lever 50 times or 30 minutes had elapsed, whichever occurred first. Rats stayed in this condition for 3 to 5 days, until they successfully pressed the lever 50 times in less than 30 min for three consecutive days.

During the training phase, rats were exposed to FI 15, 30 or 60 s food reinforcement schedules during 30 sessions each. Each session lasted 60 trials (food to food intervals): approximately 15 min for the FI 15 s, 30 min for the FI 30 s, and 60 min for the FI 60 s (the sessions could last 1 or 2 minutes more if the subjects took longer to press the lever than the exact FI value). Depending on the FI schedule, 15, 30 or 60 s after the 60th reinforcer the houselight was turned off, the lever was retracted, and the session ended.

Data analysis

Lever presses and licks were recorded, and response rates (responses per minute) were calculated. Two commonly used timing measures were computed: post-reinforcement pause and breakpoint. The post-reinforcement pause (PRP) is the time from the beginning of the trial (i.e. reinforcer delivery at the end of the previous trial) to the first response, and it was calculated using an Excel Macro, with the constrain that if the PRP < .5 s, the second response was used to calculate the PRP in order to avoid using a residual response from the previous trial. Longer PRPs would indicate a better adjustment to the FI schedule. The breakpoint (BP) is the time at

which the response rate in an interval changes from a low response rate to a high response rate. It was calculated using an Excel Macro that ran the equation described by Guilhardi and Church (2004), in which the BP is the response time that maximizes the expression in the equation: $BP = \max (d_1|r_1 - r| + d_2|r_2 - r|)$, where d_1 is the duration before the breakpoint, d_2 is the duration after the breakpoint, r is the overall response rate of the trial, r_1 is the response rate during d_1 , and r_2 is the response rate during d_2 . In order to calculate the breakpoint, the trial had to have at least 4 lever presses. The breakpoint corresponds to the average values of d_1 (defined after the function was maximized) across all intervals in each session. Breakpoints occurring later on the interval would indicate a better adjustment to the FI schedule. Also, the peak of licks was calculated as the 1 s bin at which the higher licking rate was observed for each session and subject. The time of the last lick and the peak of licks were also calculated using Excel Macros.

In order to evaluate steady-state performance on FI schedules, data from the last 5 sessions (26 to 30) were analyzed using Bayesian Linear Mixed-effects Models (BLMMs). Linear Mixed-effects Models have been increasingly recommended for its use in behavioral science as they account for both within- and between-subjects variance, deal adequately with nested and/or unbalanced data, and overall decrease the rates of Type I error (Boisgontier & Cheval, 2016; Harrison et al., 2018). Additionally, the Bayesian approach was selected as it emphasizes the evidence over the decisions, allows for a more intuitive way to compare models, and to construct knowledge based on previous studies (Wagenmakers et al., 2018; Young, 2019; for a tutorial on how to conduct BLMMs on R, see Franke & Roettger, 2019).

BLMMs were fitted to the previously described measures as a function of groups and/or FI values using the brms package (Bürkner, 2017, 2018) on R (R Core Team, 2012; Rstudio Team, 2020). Models included random intercepts for subjects and/or sessions. Different models were

constructed for each measure, and compared with each other and with a null model, using Bayes factors. The \hat{R} statistic was calculated for each estimated parameter to evaluate its reliability; values within the range of 1 ± 0.1 indicated reliable convergence of the model for that parameter (Sorensen et al., 2016), all estimated parameters fell into this range. The expected values (\mathbb{E}) (i.e. the mean of the posterior distribution of the model), standard error, and 95 % credible interval (CI) for each parameter of the model (intercept and slope(s), μ_x) were calculated. The diagnostic and posterior summary statistics of the estimated parameters of the Bayesian Linear Mixed-effects Models described in the results section, and the equation for the best-fitting model for each analysis, as well as the details of their simulations are included in the supplemental material. The posterior probability ($P(\delta)$) of a slope being more (or less) than zero in 95% of the samples, was interpreted as compelling evidence for the difference between the intercept and the slope to be greater (or lower) than zero (Franke & Roettger, 2019).

Additionally, Bayesian Pearson's correlation tests were calculated for each subject to compare the PRP and the time of the last lick using JASP (JASP Team, 2020). Bayes factors (BF) are interpreted as follows: $BF_{10} > 1$ denotes evidence for the alternative hypothesis, $BF_{10} < 1$ indicates evidence for the null hypothesis, and $BF_{10} = 1$ shows there is no evidence for either the null or alternative hypothesis (Wagenmakers et al., 2011). Results of the individual Bayesian Pearson's correlation analysis and visual representation of the correlations are included in the supplemental material.

Additional materials, including datasets, codes, and the posterior distributions and results of the posterior predictive checks for each BLMM model may be retrieved from:

https://github.com/GELopezTolsa/Timing_and_SIB.

Results

The aim of this study was to compare the performance of rats on different values of FI schedules, when they had or did not have the opportunity to engage in schedule-induced drinking. Figure 1 shows the average response rate (responses/min) for each session and group throughout the experiment. Lever-pressing rates (graph A) were quite similar for all groups, except for W60 (filled triangles) which was lower during the first four to five sessions of the experiment and NW15 (empty circles) which was higher from session 10 onwards. The best-fitting BLMM indicated that the lever-pressing rate in the last five sessions (26-30) was a function of group and FI value. The lever-pressing rate was lower for the W groups compared to the NW groups ($\mathbb{E}(\mu_{NW}) = 4.98$, $CI = [-2.62, 12.94]$, $P(\delta) > 0 = .905$), and it was higher for the FI 15 s groups than for the FI 30 s ($\mathbb{E}(\mu_{W30}) = -3.66$, $CI = [-13.11, 5.34]$, $P(\delta) < 0 = .788$) and the FI 60 s ($\mathbb{E}(\mu_{W60}) = -1.52$, $CI = [-10.52, 6.99]$, $P(\delta) < 0 = .631$) groups; although the posterior probabilities of the slopes showed that there is not enough evidence that these differences are greater than zero. Graph B in Figure 1 displays the spout-licking rate for each group and session throughout the experiment. It can be observed that licking rate increased from sessions 1 to 10 for all groups, although it continued to increase for group W15 towards the second half of the experiment. Rats in the W30 and W60 groups showed similar licking rates, whereas rats in the W15 group showed a higher licking rate. The best-fitting model indicated that licking rate was a function of the FI value, and there was compelling evidence for the licking rate to be lower for the W30 ($\mathbb{E}(\mu_{W30}) = -50.56$, $CI = [-108.74, 8.9]$, $P(\delta) < 0 = .953$) and W60 ($\mathbb{E}(\mu_{W60}) = -58.02$, $CI = [-112.99, -0.73]$, $P(\delta) < 0 = .977$) groups than for the W15 group.

Insert Figure 1 about here

Figure 2 shows the mean temporal distribution of lever presses and spout licks in the last five sessions for both groups of each FI schedule. Graph A shows the distribution of responses

for the FI 15 s groups, Graph B for the FI 30 s groups, and Graph C for the FI 60 s groups. Licks occurred in the first part of the interval for the three W groups, and lever pressing reliably began when licking ended for the W30 and W60 groups. Regarding the W15 group, licking did not reach zero-levels at any point during the inter-reinforcement interval (except the first very few seconds), but it occurred throughout the interval, as confirmed by the time of the last lick for that group (the range of the time of the last lick was 5.14 to 16.97 for the W15 group, see later Figure 3, graph C). The peak of licks occurred later the longer the FI value: 6.73 ± 0.55 (range: 4-10) for the W15 group, 8.9 ± 0.88 (range: 6-14) for the W30 group, and 11.93 ± 2.82 (range: 5-45) for the W60 group. The best-fitting BLMM indicated that the peak of licks was a function of the FI, and that there was compelling evidence for the peak to occur later for the W60 group than for the W15 group ($\mathbb{E}(\mu_{W60}) = 5.09$, $CI = [1.06, 9.06]$, $P(\delta) > 0 = .994$), but there was not sufficient evidence for the peak of the W30 group to occur later than for the W15 group ($\mathbb{E}(\mu_{W30}) = 2.08$, $CI = [-2.41, 6.4]$, $P(\delta) > 0 = .835$). Also, licking lasted longer, the longer the FI value, especially for the W60 group, as was also confirmed by the time of the last lick (see later graph C of Figure 3). Regarding the distribution of lever-presses, the FI scallop was visible for all groups: there was little responding at the beginning of the interval and a higher response rate towards the end of the interval. Subjects in groups NW15 and NW30 showed a steeper record than their homologous W groups (circles and squares, respectively), whereas W60 showed a steeper record than NW60 rats (triangles); although the breakpoints were quite similar among groups, as will be described next.

Insert Figure 2 about here

In order to measure accuracy on the performance of subjects, two traditional timing measures were calculated: post-reinforcement pause (PRP) and breakpoint (BP); additionally, the

time of the last lick (and the peak of licks as shown in Figure 2) was calculated for each trial and subject. The PRP is the time elapsed since the beginning of the interval (the delivery of the previous reinforcer) until the first lever press. As can be observed in graph A of Figure 3, PRPs were longer, the longer the FI value, and they were higher for the W groups than for the NW groups in the three FI values. The best-fitting model indicated that the PRP was a function of group and FI value. There was compelling evidence that the PRP was lower for the NW than for the W groups ($\mathbb{E}(\mu_{NW}) = -2.46$, $CI = [-5.26, 0.28]$, $P(\delta) < 0 = .96$), with this difference decreasing as the FI value increased: 7.55 ± 0.3 (Mean \pm S.E.M.; range: 5.06-11.1) vs. 10.81 ± 0.38 (range: 6.49-15.68) for the NW15 and W15 groups, respectively; 14.5 ± 0.89 (range: 5.73-23.38) vs. 17.3 ± 0.41 (range: 12.88-20.97) respectively for the NW30 and W30 groups; and 27.58 ± 1.05 (range: 17.69-42.58) vs. 28.98 ± 1.11 (range: 13.23-41.73) for the NW 60 and W60 groups, respectively. As expected, there was also compelling evidence for the PRP of FI 30 s ($\mathbb{E}(\mu_{W30}) = 6.88$, $CI = [3.28, 10.4]$, $P(\delta) > 0 = 1$) and FI 60 s ($\mathbb{E}(\mu_{W60}) = 19.19$, $CI = [15.95, 22.5]$, $P(\delta) > 0 = 1$) groups to be longer than for the FI 15 s groups.

Insert Figure 3 about here

The BP is the time at which the response rate changes from a low rate to a high rate. Graph B in Figure 3 shows the mean BP for each group in the last five sessions. The BP increased as the FI value increased, and it occurred at approximately two-thirds of the total time of the interval, nevertheless, it should be considered that in order to calculate it, at least 3 lever presses per trial are needed, so it was not calculated for all trials for all subjects (particularly, it was calculated for a mean of 30 trials for the W15 group, and for about 50 trials per session for the other groups). The best fitting model indicated that the BP was a function of group and FI value, and that there was not sufficient evidence of the BP to be lower for the NW than for the W

groups ($\mathbb{E}(\mu_{NW}) = -0.32$, $CI = [-1.46, 0.83]$, $P(\delta) < 0 = .712$). There was compelling evidence for the BPs of FI 30 s ($\mathbb{E}(\mu_{W30}) = 9.94$, $CI = [8.37, 11.54]$, $P(\delta) > 0 = 1$) and FI 60 s ($\mathbb{E}(\mu_{W60}) = 28.36$, $CI = [26.96, 29.83]$, $P(\delta) > 0 = 1$) groups to be higher than for the FI 15 s groups, as expected.

For the purpose of investigating the relationship between SID and lever pressing, the time of the last lick in each trial was calculated. Graph C in Figure 3 shows that the time of the last lick was similar between W15 and W30 groups, 11.1 ± 0.51 (range: 5.14-16.97) and 12.5 ± 0.27 (range: 9.81-15.06), respectively, but it was almost twice as long for the rats in the W60 group: 21.33 ± 1.37 (range: 10.65-41.58). The best-fitting BLMM indicated that the time of the last lick was a function of the FI value, there was compelling evidence of the time of the last lick to be longer for the W60 group than for the W15 group ($\mathbb{E}(\mu_{W60}) = 10.31$, $CI = [4.2, 16.35]$, $P(\delta) > 0 = .999$), but there was not sufficient evidence for the difference between W15 and W30 to be greater than zero ($\mathbb{E}(\mu_{W30}) = 1.37$, $CI = [-4.9, 7.97]$, $P(\delta) > 0 = .661$).

In order to get a quantitative measure of any relationship between SID and lever pressing on a FI schedule, Pearson's correlations between the time of the last lick and the PRP were calculated. Most subjects (except W60-5) showed positive correlations between the two measures, although the strength of those correlations decreased as the FI value increased: a mean r value of $.58 \pm .08$ (range: .23 - .82) for W15 group, a mean r value of $.36 \pm .08$ (range: .13 - .68) for W30, and a mean r value of $.22 \pm .06$ (range: -.007 - .45) for W60. Nevertheless, the credible intervals show only positive values for the W15 and W30 groups, and for five of the eight subjects in the W60 group (individual values are shown in the supplemental material). It should also be considered that the correlation could be affected by the time it took to the rat to move from the water bottle to the lever press, which might have been interfered with grooming

or exploring behaviors that were not recorded and that could have taken different times during different trials.

Discussion

Lever pressing and SID developed during the first few sessions until they reached a stable rate towards the last few sessions, as has been previously reported (Álvarez et al., 2016; Camacho & Cabrera, 2014; Falk, 1971; López & Menez, 2012). Lever-pressing rate was similar among groups, although slightly higher for the NW groups; whereas licking rate was higher for W15 than for the other W groups. Licking rate, when measured in licks/min, is often reported higher for FI 30 s than for FI 15 s, and lower for FI 60 s (Flores & Pellón, 1997; Pellón et al., 2020), but on many occasions the highest rate of responding corresponds to the highest reinforcement frequency (Castilla & Pellón, 2013; Íbias & Pellón, 2011, 2014), as has been the case in the present study. Based on reinforcement frequency as a controlling variable, it is reasonable to find out a positive relation between response and reinforcement rates, and when this does not occur it could be likely due to response competition interfering with licking (such as from lever pressing, magazine entering or eating).

PRP and breakpoint are attempts to summarize quantitatively the performance on FI schedules and have been used to measure time discrimination on FI schedules (Buriticá & dos Santos, 2017; Guilhardi & Church, 2004). PRPs were longer for the W than for the NW groups, but that difference was larger between the FI 15 s groups than between the FI 30 s and FI 60 s groups. These findings are similar to data reported by Sanabria et al. (2009), who observed that behaving according to a concurrent schedule improved timing during FI 15 s, but not during FI 60 s. Furthermore, Killeen (1969) compared the performance of pigeons under a fixed-ratio schedule and their yoked subjects that were responding under a “variable-interval” schedule

(they received a reinforcer after the first response when the lead animal met the ratio criterion). He found that PRPs were the same for both groups, meaning that pigeons started to respond at the same time, although the pecks of yoked animals did not have much effect on reinforcement procurement. In general, the length of the PRP depends on the length of the FI, so it is possible that differences between W and NW groups were smaller between the FI 30 and FI 60 s groups, because SID occurred for a similar time than the duration of the PRP in their corresponding NW groups, whereas for the W15 group, the time of PRP was highly affected compared to the NW15 group, because SID lasted longer than the expected PRP for that schedule. It is well established that behaviors compete with each other (Baum, 2012; Baum & Grace, 2020; Pellón & Killeen, 2015), and because SID usually occurs in the first 10-20 s of the inter-reinforcement interval, it makes sense that it interfered with lever pressing only in the FI 15 s schedule. Regardless of the length of the PRP, it seems that once the rats started pressing the lever they did not go back to drinking until they obtained the next reinforcer, as has been previously reported in other studies (Laties et al., 1969; Segal & Holloway, 1963).

Although the breakpoints occurred slightly earlier for the NW than for the W groups, there was not enough evidence of that difference to be greater than zero; this may indicate that SID did not interfere with timing processes on lever pressing. It should be considered that breakpoints were only calculated for half of the trials for the W15 group because in the rest of the trials less than four lever presses were performed before the reinforcer was available. In the trials in which less than four lever presses were performed before the reinforcer, it seems that lever pressing was controlled by competition with SID, as suggested by the positive correlation between the last lick and the PRP for the W15 group, rather than by the process of timing.

Moreover, the results regarding the PRP and the breakpoint support the behavioral-pattern hypothesis proposed by Killeen and Fetterman (Fetterman et al., 1998; Killeen & Fetterman, 1988) and Ruiz et al. (2016): rats go from one state of behavior (drinking) to the other (lever-pressing), and PRPs reflect the change from SID to lever pressing (see also, Baum & Grace, 2020; Sanabria et al., 2009). Rats in the NW groups probably engaged in other activities that were not measured here during the PRP, but rats in all groups behaved similarly during the rest of the interval.

Lever presses and licks showed a difference in their distributions: lever presses manifested the scalar property, as indicated by the time of the breakpoint, which was equivalent to two-thirds of the FI value for all groups (Church et al., 1994; Guilhardi & Church, 2004), whereas the distribution of licks was apparently similar among groups (Flores & Pellón 1997). Nevertheless, a careful consideration of the time for the peak of licks and the time of the last lick showed that licking lasted more specially at the longest FI value, suggesting that the duration of the interval was affecting SID in a way, but not in the scalar manner in which it affected lever pressing (see also Castilla & Pellón, 2013).

The LeT model assumes that the same number of states is repeated in intervals of different lengths, so as the time of occurrence of the last behavior changes, so will the time during which the previous behavioral states are active (for example, each state should be active for twice the time in a FI 30 s than in a FI 15 s schedule for the same organism in similar circumstances), thus the activation of the behavioral states should also manifest the scalar property (Machado et al., 2009; Vasconcelos et al., 2017), but data from the current study seem to go against that hypothesis. Nevertheless, this assumption relates more to a mathematical simplification of the model than to an assumption of how actually the states relate to behavior (Machado et al., 2009).

It might be the case, given its short duration, that in W15 there is only one additional behavioral state (i.e. SID), but as the interval is lengthened, more behavioral states are added into the behavioral pattern before the operant response, as supported by the weak correlations between the time of the last lick and the PRP observed in the W30 and W60 groups, compared to the stronger correlation in the W15 group. This assumption would also be supported by studies in which changes in the availability of objects for the organisms to interact with result in changes of the behavioral patterns that they develop (Roper, 1978; Segal, 1969; Skuban & Richardson, 1975; Staddon & Ayres, 1975), or by the idiosyncrasy of the behavioral patterns developed when non-target behaviors are required for reinforcement (Cleaveland et al., 2003; Machado & Keen, 1999; Skinner, 1948; Staddon & Simmelhag, 1971).

One of the arguments against schedule-induced behaviors being the same as operants is their temporal location early in the inter-reinforcement intervals (Falk, 1971; López-Crespo et al., 2004), in any case the individual temporal distribution of each behavior may not be as relevant as its interaction with other behaviors, where the end of one response may lead to the start of the next response in the behavioral pattern, as supported by the positive correlations between the time of the last lick and the PRP, especially for the W15 group, and the higher amount of trials with less than four responses showed by the W15 group, compared to the other groups.

Lejeune et al. (1998) observed that gerbils did not emit the same amount of responses for the same time in every interval, so they concluded that schedule-induced behaviors did not mediate timed responses, but data from the present study show that even if licking did not occur for the same period on every interval, it was consistently followed by lever pressing, and in some cases, the start of lever pressing (most cases for the W15 group) was modulated by the ending of

SID. This adds-up to other studies that have shown patterns of schedule-induced behaviors determine choice (Cleaveland et al., 2003; Machado & Keen, 1999).

Why then rats only drink mostly in the first 10-20 s of the interval? One possibility is that rats can consume only a limited amount of water per food delivery (it is, after all, a consummatory behavior, even if it is controlled by the periodic delivery of reinforcement – see within-session changes in licking reported by Íbias & Pellón, 2011), thus they drink *as much as they can* for that food episode, and spend the rest of the interval pressing the lever. It could also be hypothesized that the effect of engaging in schedule-induced behavior on timing would depend on the type of schedule-induced behavior subjects have the opportunity to engage in. For example, in the present case, SID is a behavior that mainly occurs in the first 20 s, but if rats had the opportunity to engage in schedule-induced wheel running, which is a behavior that may occur for more than 60 s per inter-reinforcement interval (Gutiérrez-Ferre & Pellón, 2019), its development would probably affect performance on longer FI schedules. According to the data presented in this study, schedule-induced behaviors seem to influence the behavioral pattern which organisms develop during temporal tasks, but this seems to not directly affect quantitative timing measures. This type of results leads to the question of what we are really measuring when we talk about temporal learning and/or time estimation (see Sanabria et al. 2009, for a case in which motivational variables, rather than timing, may account for better results in temporal tasks). As Cleaveland et al. (2003) pointed out, scientists in the field of the analysis of behavior are usually only concerned with measuring one specific behavior like a lever press or a key peck, without paying attention to the actual organism behaving.

Lejeune et al. (1998) stated that schedule-induced behaviors do not mediate timed responses and proposed a two-process account for timed behavior. One process of timing

responses with a 'counter' and a second process with an arousal mechanism that relates activity to reinforcement rate accounting for changes in their number and rate. But what if the first process does not really occur or occurs differently? It may be simpler to propose a single process that applies to all types of behaviors, in which available behaviors are just induced (Baum, 2012; see also Cowie et al., 2011, 2017), but data in the present study show that some behaviors fit and others do not fit the scalar property, therefore appearing to suggest a second process in addition to induction, for which we suggest that the strength of modulation by reinforcement depends upon response-reinforcer contiguity (Killeen & Pellón, 2013).

In the case of the current study, the delivery of reinforcement was dependent on emission of lever pressing at a specific time, so reinforcers should have exerted a stricter control on when lever pressing would occur than on when SID and other non-measured behaviors would occur. The delivery of reinforcement increases the occurrence of reinforcer-related behaviors that will be later organized into a behavioral pattern (Baum, 2012; Pellón & Killeen, 2015) that leads to the occurrence of the target operant behavior at a specific time, but not that of other behaviors. Because of the lack of explicit response-reinforcer contingency, these other behaviors are not forced to occur at a specific time, so there is no reason to expect them to show the scalar property. Perhaps the imposition of a response-reinforcer contingency may turn the response under more strict control than the mere contiguity of responses with reinforcement (even more in the case of extended contiguity), thus resulting in a temporal control that meets the scalar property. This proposal can be tested by putting behaviors other than lever pressing under contingent control of the reinforcer, so that imposing, for example, a response-reinforcer contingency on drinking should result in drinking now meeting the scalar property as well.

In general, data in this experiment does not support the hypothesis that the development of SID in FI food schedules has a direct effect on timing, nevertheless, it provides interesting information on how competition among behaviors sometimes exerts more control than timing on when an operant behavior occurs, as observed in the data of the W15 group. Further exploration on how behaviors compete with each other and shape each other's distributions (Pellón & Killeen, 2015) might lead to a better understanding of the role of schedule-induced behaviors, and on the interaction between induction (Baum, 2012, 2015; Cowie et al., 2011, 2017) and reinforcement (Killeen & Pellón, 2013; Ruiz et al., 2016) to the acquisition and maintenance of behavior (López-Tolsa, 2019). Although it is not assumed that the "purpose" of schedule-induced behaviors is to aid timing (Killeen et al., 1997), the sequential dependency in the behavioral patterns may turn into a discriminative property that determines the performance of organisms on temporal tasks (Laties et al., 1969; Machado et al., 2009). This view is consistent, to a large degree, with behavioral timing theories proposed by Killeen (Killeen, 1975; Killeen & Fetterman, 1988) and Machado (1997). The goal of this study was not to test the predictions of LeT (Machado, 1997), or any other timing model, but rather, to make evident the mechanisms that are inferred in such models.

In sum, a better understanding of temporal learning would require an analysis of behavior that takes a closer look to organisms behaving in a continuum, thus making opportunity for reinforcement to act across a wider behavioral repertoire. Timing seems to consist in the temporal organization of available behaviors that leads to a specific behavior occurring at a specified time, which researchers only looking at that behavior interpret as 'accurate timing'. Organisms are always behaving, the environment provides the opportunities for some behaviors to be induced, and the schedule of reinforcement shapes their distribution.

Acknowledgements

The conduct of the experimental work and the preparation of manuscript were funded by grant PSI2016-80082-P (Ricardo Pellón: Principal Investigator) from the Spanish Government (Ministerio de Economía y Competitividad, Secretaría de Estado de Investigación, Desarrollo e Innovación). Gabriela E. López-Tolsa was awarded a Scholarship to undertake PhD-level studies abroad (255325/383739) by the Mexican Government (Consejo Nacional de Ciencia y Tecnología). We thank Antonio Rey for excellent technical support, Esmeralda Fuentes and Patricia Rick for their help with data collection, Armando Machado for his feedback on initial data analysis, and Peter R. Killeen for inspiration.

References

- Álvarez, B., Íbias, J., & Pellón, R. (2016). Reinforcement of schedule-induced drinking in rats by lick-contingent shortening of food delivery. *Learning and Behavior*, *44*, 329-339. doi: <http://dx.doi.org/10.3758/s13420-016-0221-6>
- Ardoy, J., & Pellón, R. (2004). Effects of withholding the opportunity to press the operant lever on the maintenance of schedule-induced drinking in rats. *Revista Mexicana de Análisis de la Conducta*, *30*, 79-91.
- Baron, A., & Leinenweber, A. (1994). Molecular and molar analyses of fixed-interval performance. *Journal of the Experimental Analysis of Behavior*, *61*, 11-18. <https://doi.org/10.1901/jeab.1994.61-11>
- Baum, W. M. (2012). Rethinking reinforcement: Allocation, induction and contingency. *Journal of the Experimental Analysis of Behavior*, *97*, 101-124. <https://doi.org/10.1901/jeab.2012.97-101>
- Baum, W. M. (2015). The role of induction in operant schedule performance. *Behavioural Processes*, *114*, 26-33. <https://doi.org/10.1016/j.beproc.2015.01.006>
- Baum, W. M. (2018). Three laws of behavior: Allocation, induction, and covariance. *Behavior Analysis: Research and Practice*, *18*, 239-251. <http://dx.doi.org/10.1037/bar0000104>
- Baum, W. M., & Grace, R. C. (2020). Matching theory and induction explain operant performance. *Journal of the Experimental Analysis of Behavior*, *113*, 390-418. <https://doi.org/10.1002/jeab.583>
- Boisgontier, M. P., & Cheval, B. (2016). The anova to mixed model transition. *Neuroscience & Biobehavioral Reviews*, *68*, 1004-1005. <https://doi.org/10.1016/j.neubiorev.2016.05.034>

- Bruner, A., & Revusky, S. H. (1961). Collateral behavior in humans. *Journal of the Experimental Analysis of Behavior*, 4, 345-350. <https://doi.org/10.1901/jeab.1961.4-349>
- Bürkner, P. (2017). “brms: An R Package for Bayesian Multilevel Models Using Stan.” *Journal of Statistical Software*, 80(1), 1–28. doi: 10.18637/jss.v080.i01
- Bürkner, P. (2018). “Advanced Bayesian Multilevel Modeling with the R Package brms.” *The R Journal*, 10(1), 395–411. doi: 10.32614/RJ-2018-017
- Buriticá, J., & dos Santos, C. V. (2017). Reinforcement value and fixed-interval performance. *Journal of the Experimental Analysis of Behavior*, 108, 151-170. <https://doi.org/10.1002/jeab.279>
- Camacho Candia, J. A., & Cabrera González, F. (2014). Allocation of behavior in a simple discrimination task. *Conductual, International Journal of Interbehaviorism and Behavior Analysis*, 2, 4-16.
- Castilla, J. L., & Pellón, R. (2013). Combined effects of food deprivation and food frequency on the amount and temporal distribution of schedule-induced drinking. *Journal of the Experimental Analysis of behavior*, 100(3), 396-407.
- Church, R. M., Meck, W. H., & Gibbon, J. (1994). Application of scalar timing theory to individual trials. *Journal of Experimental Psychology: Animal Behavior Processes*, 20, 135-155. <http://dx.doi.org/10.1037//0097-7403.20.2.135>
- Cleaveland, J. M., Jäger, E., Rößner, & Delius, J. D. (2003). Ontogeny has a phylogeny: background to adjunctive behaviors in pigeons and budgerigars. *Behavioural Processes*, 61, 143-158. doi: 10.1016/S0376-6357(02)00187-0

- Cowie, S., Davison, M., & Elliffe, D. (2011). Reinforcement: food signals the time and location of future food. *Journal of the Experimental Analysis of Behavior*, *96*, 63-86.
<https://doi.org/10.1901/jeab.2011.96-63>
- Cowie, S., Davison, M., & Elliffe, D. (2017). Control by past and present stimuli depends on the discriminated reinforcer differential. *Journal of the Experimental Analysis of Behavior*, *108*, 184-203. <https://doi.org/10.1002/jeab.268>
- Falk, J. L. (1966). The motivational properties of schedule-induced polydipsia. *Journal of the Experimental Analysis of Behavior*, *9*(1), 19-25. <https://doi.org/10.1901/jeab.1966.9-19>
- Falk, J. L. (1971). The nature and determinants of adjunctive behavior. *Physiology & Behavior*, *6*, 577-588. [http://dx.doi.org/10.1016/0031-9384\(71\)90209-5](http://dx.doi.org/10.1016/0031-9384(71)90209-5)
- Fetterman, J. G., Killeen, P. R., & Hall, S. (1998). Watching the clock. *Behavioural Processes*, *44*, 211-222. [http://dx.doi.org/10.1016/S0376-6357\(98\)00050-3](http://dx.doi.org/10.1016/S0376-6357(98)00050-3)
- Flores, P., & Pellón, R. (1995). Rate-dependency hypothesis and the rate-decreasing effects of d-amphetamine on schedule-induced drinking. *Behavioural Pharmacology*, *6*(1), 16-23.
<https://doi.org/10.1097/00008877-199501000-00004>
- Flores, P., & Pellón, R. (1997). Effects of d-amphetamine on temporal distributions of schedule-induced polydipsia. *Pharmacology Biochemistry and Behavior*, *57*, 81-87.
[https://doi.org/10.1016/S0091-3057\(96\)00131-1](https://doi.org/10.1016/S0091-3057(96)00131-1)
- Flory, R. K. (1971). The control of schedule-induced polydipsia: frequency and magnitude of reinforcement. *Learning and Motivation*, *2*(3), 215- 227. doi:10.1016/0023-9690(71)90022-1
- Franke, M., & Roettger, T. B. (2019). Bayesian regression modeling (for factorial designs): A tutorial. PsyArXiv. 10.31234/osf.io/cdxv3

- Guilhardi, P. & Church, R. M. (2004). Measures of temporal discrimination in fixed-interval performance: A case study in archiving data. *Behavior Research Methods, Instruments, & Computers*, *36*, 661–669. <https://doi.org/10.3758/BF03206548>
- Gutiérrez-Ferre, V. E., & Pellón, R. (2019). Wheel running induced by intermittent food schedules. *Psicológica*, *40*, 46-61. <https://doi.org/10.2478/psicolj-2019-0004>
- Harrison, X. A., Donaldson, L., Correa-Cano, M. E., Evans, J. Fisher, D.N., Goodwin, C.E.D., Robinson, B.S., Hodgson, D.J., & Inger, R. (2018). A brief introduction to mixed effects modelling and multi-model inference in ecology. *PeerJ*. E4794. <https://doi.org/10.7717/peerj.4794>
- Íbias, J., & Pellón, R. (2011). Schedule-induced polydipsia in the Spontaneously Hypertensive Rat and its relation to impulsive behaviour. *Behavioural Brain Research*, *223*, 58-69. <http://dx.doi.org/10.1016/j.bbr.2011.04.017>
- Íbias, J., & Pellón, R. (2014). Different relations between schedule-induced polydipsia and impulsive behaviour in the Spontaneously Hypertensive Rat and in high impulsive Wistar rats: Questioning the role of impulsivity in adjunctive behaviour. *Behavioural Brain Research*, *271*, 184-194.
- JASP Team (2020). JASP (Version 0.14.1) [Computer software].
- Killeen, P. (1969). Reinforcement frequency and contingency as factors in fixed-ratio behavior. *Journal of the Experimental Analysis of Behavior*, *12*, 391-395. <https://doi.org/10.1901/jeab.1969.12-391>
- Killeen, P. R. (1975). On the temporal control of behavior. *Psychological Review*, *82*, 89-115. <http://dx.doi.org/10.1037/h0076820>

- Killeen, P. R. (2014). A theory of behavioral contrast. *Journal of the Experimental Analysis of Behavior, 102*, 363-390. <https://doi.org/10.1002/jeab.107>
- Killeen, P. R., Fetterman, J. G. & Bizo, L. A. (1997). Time's causes, in Bradshaw, C. M., Szabadi, E. (Eds.), *Time and behaviour: Psychological and neurobehavioural analyses*. Amsterdam: Elsevier.
- Killeen, P. R., & Fetterman, J. G. (1988). A behavioral theory of timing. *Psychological Review, 95*, 274-293. <http://dx.doi.org/10.1037/0033-295X.95.2.274>
- Killeen, P. R., & Pellón, R. (2013). Adjunctive behaviors are operants. *Learning & Behavior, 41*, 1-24. <http://dx.doi.org/10.3758/s13420-012-0095-1>
- Laties, V. G., Weiss, B., & Weiss, A. B. (1969). Further observations on overt "mediating" behavior and the discrimination of time. *Journal of the Experimental Analysis of Behavior, 12*, 43-57. <https://doi.org/10.1901/jeab.1969.12-43>.
- Lawler, C. P., & Cohen, P. S. (1992). Temporal patterns of schedule-induced drinking and paw grooming in rats exposed to periodic food. *Animal Learning & Behavior, 20*, 266-280. <https://doi.org/10.3758/BF03213381>
- Lejeune, H., Cornet, S., Ferreira, M. A., & Wearden, J. H. (1998). How do Mongolian gerbils (*Meriones unguiculatus*) pass the time? Adjunctive behavior during temporal differentiation in gerbils. *Journal of Experimental Psychology: Animal Behavior Processes, 24*, 352-368. <https://doi.org/10.1037/0097-7403.24.3.352>
- Lejeune, H., & Wearden, J. H. (1991). The comparative psychology of fixed-interval responding: some quantitative analyses. *Learning and Motivation, 22*, 84-111. [https://doi.org/10.1016/0023-9690\(91\)90018-4](https://doi.org/10.1016/0023-9690(91)90018-4)

- López, F. (2012). Aprendizaje y control temporal: Adquisición y transferencia. In P. Guilhardi, M. Menez y F. López (Eds.), *Tendencias en el estudio contemporáneo de la estimación temporal* (pp. 13-38). Universidad Nacional Autónoma de México.
- López, F., & Menez, M. (2005). Effects of reinforcement history on response rate and response pattern in periodic reinforcement. *Journal of the Experimental Analysis of Behavior*, *83*, 221-241. <http://dx.doi.org/10.1901/jeab.2005.49-04>
- López, F., & Menez, M. (2012). Transference effect of prior non-contingent reinforcement on the acquisition of temporal control on fixed-interval schedules. *Behavioural Processes*, *90*, 402-407. <http://dx.doi.org/10.1016/j.beproc.2012.04.007>
- López-Crespo, G., Rodríguez, M., Pellón, R., & Flores, P. (2004). Acquisition of schedule-induced polydipsia by rats in proximity to upcoming food delivery. *Learning & Behavior*, *32*, 491-499. <https://doi.org/10.3758/BF03196044>
- López-Tolsa, G. E. (2019). Conductas adjuntivas: entre la inducción y el reforzamiento. In I. Zepeda Riveros, F. Cabrera González, J. A. Camacho Candia & E. Camacho Gutiérrez (Eds.). *Aproximaciones al Estudio del Comportamiento y sus Aplicaciones* (pp. 109-124). Universidad de Guadalajara.
- Machado, A. (1997). Learning the temporal dynamics of behavior. *Psychological Review*, *104*, 241-265. <https://doi.org/10.1037/0033-295X.104.2.241>
- Machado, A., & Keen, R. (1999). Learning to Time (LeT) or Scalar Expectancy Theory (SeT)? A critical test of two models of timing. *Psychological Science*, *10*, 285-290. <http://dx.doi.org/10.1111/1467-9280.00152>
- Machado, A., & Keen, R. (2003). Temporal discrimination in a long operant chamber. *Behavioural Processes*, *62*, 157-182. [https://doi.org/10.1016/S0376-6357\(03\)00023-8](https://doi.org/10.1016/S0376-6357(03)00023-8)

- Machado, A., Malheiro, M. T., & Erhagen, W. (2009). Learning to time: A perspective. *Journal of the Experimental Analysis of Behavior*, *92*, 423-458.
<http://dx.doi.org/10.1901/jeab.2009.92-423>.
- Millenson, J. R., Allen, R. B., & Pinker, S. (1977). Adjunctive drinking during variable and random-interval food reinforcement schedules. *Animal Learning & Behavior*, *5*, 285-290.
<https://doi.org/10.3758/BF03209241>
- Pellón, R. (1990). Polidipsia inducida por programa: I. Definición y marco conceptual. *Revista de Psicología General y Aplicada*, *43*(3), 313-326.
- Pellón, R., & Blackman, D. E. (1987). Punishment of schedule-induced drinking in rats by signaled and unsignaled delays in food presentation. *Journal of the Experimental Analysis of Behavior*, *48*, 417-434. <http://dx.doi.org/10.1901/jeab.1987.48-417>
- Pellón, R., & Castilla, J. L. (2000). Punishment of schedule-induced drinking by lick-dependent delays in food presented at different frequencies. *The Psychological Record*, *50*, 141-153.
<https://doi.org/10.1007/BF03395347>
- Pellón, R., & Killeen, P. R. (2015). Responses compete and collaborate, shaping each others' distributions: Commentary on Boakes, Patterson, Kendig and Harris. *Journal of Experimental Psychology: Animal Learning and Cognition*, *41*, 444-451.
<http://dx.doi.org/10.1037/xan0000067>
- Pellón, R., & Pérez-Padilla, A. (2013). Response-food delay gradients for lever pressing and schedule-induced licking in rats. *Learning & Behavior*, *41*, 218-227.
<http://dx.doi.org/10.3758/s13420-012-0099-x>

- Pellón, R., López-Tolsa, G. E., Gutiérrez-Ferre, V., & Fuentes-Verdugo, E. (2020). *Schedule-induced Behavior*. In: J. Vonk, T. K. Shackelford (eds.), *Encyclopedia of Animal Cognition and Behavior*, https://doi.org/10.1007/978-3-319-47829-6_2089-1
- R Core Team (2012). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.
- Ramos, S., López-Tolsa, G. E., Sjöberg, E. A., & Pellón, R. (2019). Effect of schedule-induced behavior on responses of spontaneously hypertensive and wistar-kyoto rats in a delay-discounting task: A preliminary report. *Frontiers in Behavioral Neuroscience*, *13*, 255. <http://dx.doi.org/10.3389/fnbeh.2019.00255>
- Roper, T. J. (1978). Diversity and substitutability of adjunctive activities under fixed-interval schedules of food reinforcement. *Journal of the Experimental Analysis of Behavior*, *30*, 83-96. <http://dx.doi.org/10.1901/jeab.1978.30-83>
- Roper, T. J. (1981). What is meant by the term “schedule-induced,” and how general is schedule induction? *Animal Learning & Behavior*, *9*, 433-440. <http://dx.doi.org/10.3758/BF03209773>
- Rosellini, R. A., & Burdette, D. R. (1980). Meal size and intermeal interval both regulate schedule-induced water intake in rats. *Animal Learning & Behavior*, *8*, 647-652. <https://doi.org/10.3758/BF03197782>
- RStudio Team (2020). *RStudio: Integrated Development for R*. RStudio, PBC, Boston, MA
URL <http://www.rstudio.com/>
- Ruiz, J. A., López-Tolsa, G. E., & Pellón, R. (2016). Reinforcing and timing properties of water in the schedule-induced drinking situation. *Behavioural Processes*, *127*, 86-96. <https://doi.org/10.1016/j.beproc.2016.03.018>

- Sanabria, F., Thraillkill, E. A., & Killeen, P. R. (2009). Timing with opportunity cost: Concurrent schedules of reinforcement improve peak timing. *Learning & Behavior*, *37*, 217–229.
<https://doi.org/10.3758/LB.37.3.217>
- Segal, E. F. (1969). The interaction of psychogenic polydipsia with wheel running in rats. *Psychonomic Science*, *14*(3), 142-144. <https://doi.org/10.3758/BF03332752>
- Segal, E. F., & Holloway, S. M. (1963). Timing behavior in rats with water drinking as a mediator. *Science*, *140*, 888-889. <http://dx.doi.org/10.1126/science.140.3569.888>
- Segal, E. F., Oden, D. L., & Deadwyler, S. A. (1965). Determinants of polydipsia: IV. Free-reinforcement schedules. *Psychonomic Science*, *3*, 11-12.
<https://doi.org/10.3758/BF03342992>
- Skinner, B. F. (1948). Superstition in the pigeon. *Journal of Experimental Psychology*, *38*, 168-172. <http://dx.doi.org/10.1037/h0055873>
- Skuban, W. E., & Richardson, W. K. (1975). The effect of the size of the test environment on behavior under the two temporally defined schedules. *Journal of the Experimental Analysis of Behavior*, *23*, 271-275. <https://doi.org/10.1901/jeab.1975.23-271>
- Sorensen, T., Hochenstein, S., & Vasishth, S. (2016). Bayesian linear mixed models using stan: A tutorial for psychologists, linguistics, and cognitive scientists. *The Quantitative Methods for Psychology*, *12*. <http://doi.org/10.20982/tqmp.12.3.p175>
- Staddon, J. E. R., & Ayres, S. L. (1975). Sequential and temporal properties of behavior induced by a schedule of periodic food delivery. *Behavior*, *54*, 26-49.
<http://dx.doi.org/10.1163/156853975X00317>

- Staddon, J. E. R., & Simmelhag, V. L. (1971). The “superstition” experiment: A re-examination of its implication for the principles of adaptive behavior. *Psychological Review*, 78, 3-43. <https://doi.org/10.1037/h0030305>
- Timberlake, W., & Lucas, G. A. (1985). The basis of superstitious behavior: Chance contingency, stimulus substitution, or appetitive behavior? *Journal of the Experimental Analysis of Behavior*, 44, 279-299. <https://doi.org/10.1901/jeab.1985.44-279>
- Vasconcelos, M., Pinheiro de Carvalho, M., & Machado, A. (2017). Timing in animals: From the natural environment to the laboratory, from data to models. In *APA Handbook of Comparative Psychology: Perception, Learning, and Cognition* (ed. J. CALL), pp. 509–534. American Psychological Association.
- Wagenmakers, E. J., Wetzels, R., Borsboom, D., & van der Maas, H. L. J. (2011). Why psychologists must change the way they analyze their data: The case of Psi: Comment on Bem (2011). *Journal of Personality and Social Psychology*, 100(3), 426-432.
- Wagenmakers, E. J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review*, 25, 35-57. <http://doi.org/10.3758/s13423-017-1343-3>
- Young, M. E. 2019. Bayesian data analysis as a tool for behavior analysts. *Journal of the Experimental Analysis of Behavior*, 111, 225-238. <http://doi.org/10.1002/jeab.512>

Tables**Table 1***Characteristics of each experimental group*

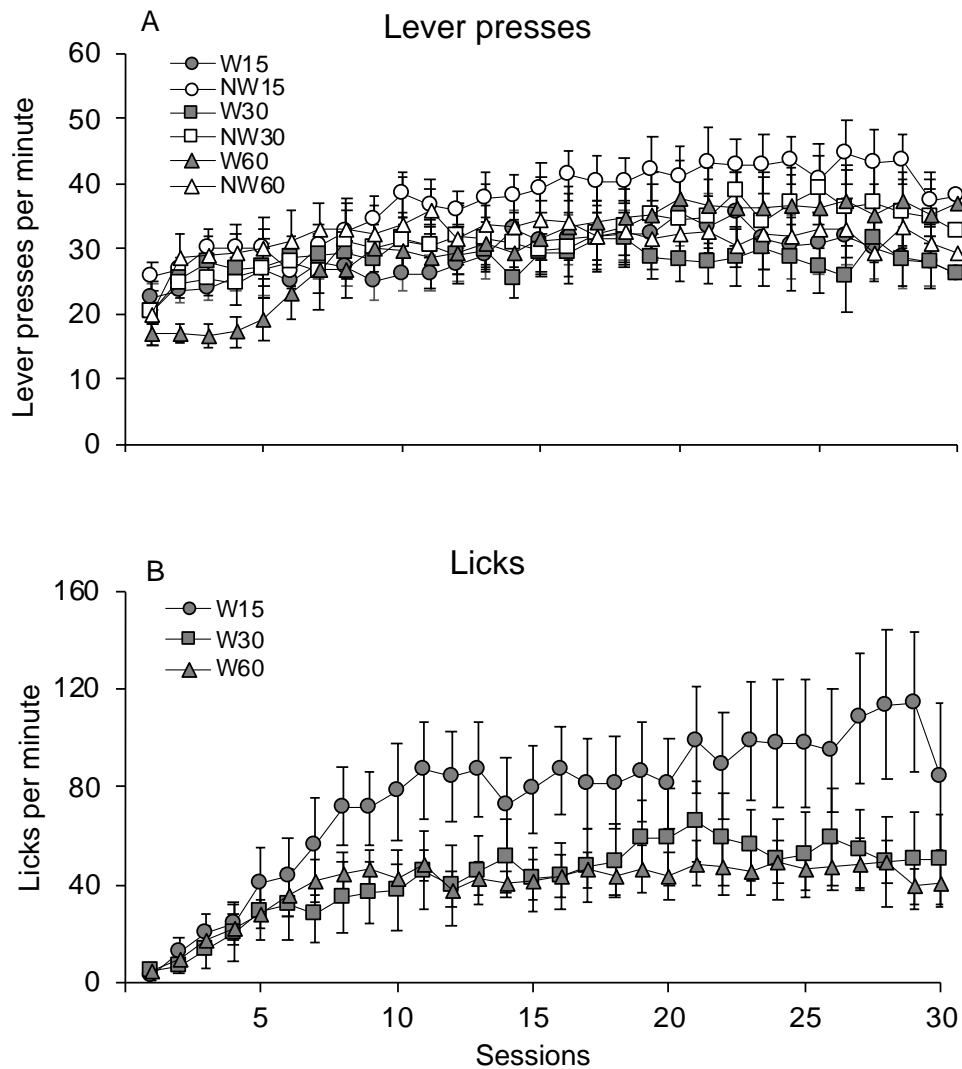
Group	FI value	Water/No water	N
W15	15 s	Water	8
NW15	15 s	No water	8
W30	30 s	Water	6
NW30	30 s	No water	6
W60	60 s	Water	8
NW60	60 s	No water	8

Note. FI = Fixed Interval; W = Water; NW = No Water; n = sample.

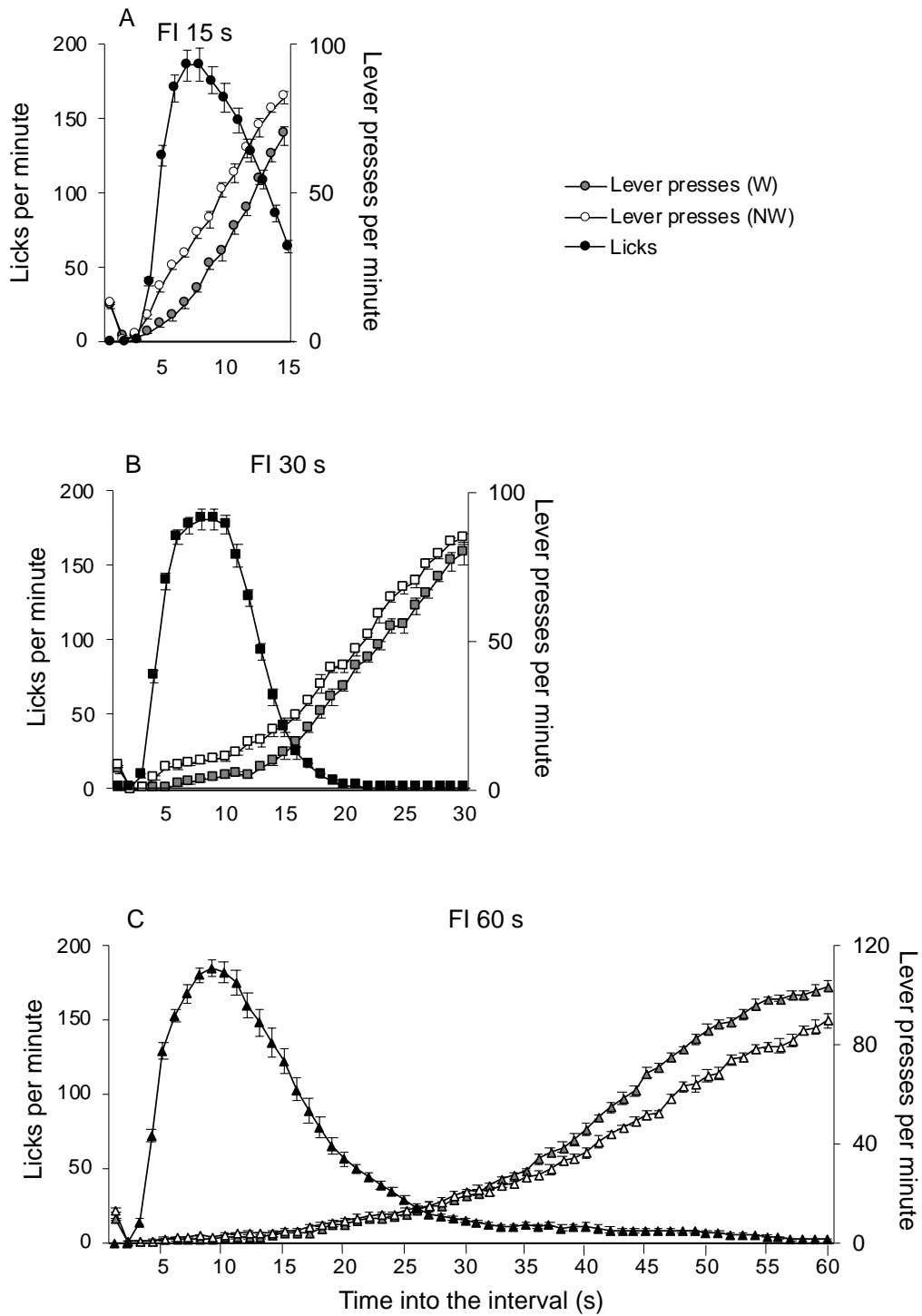
Figures

Figure 1

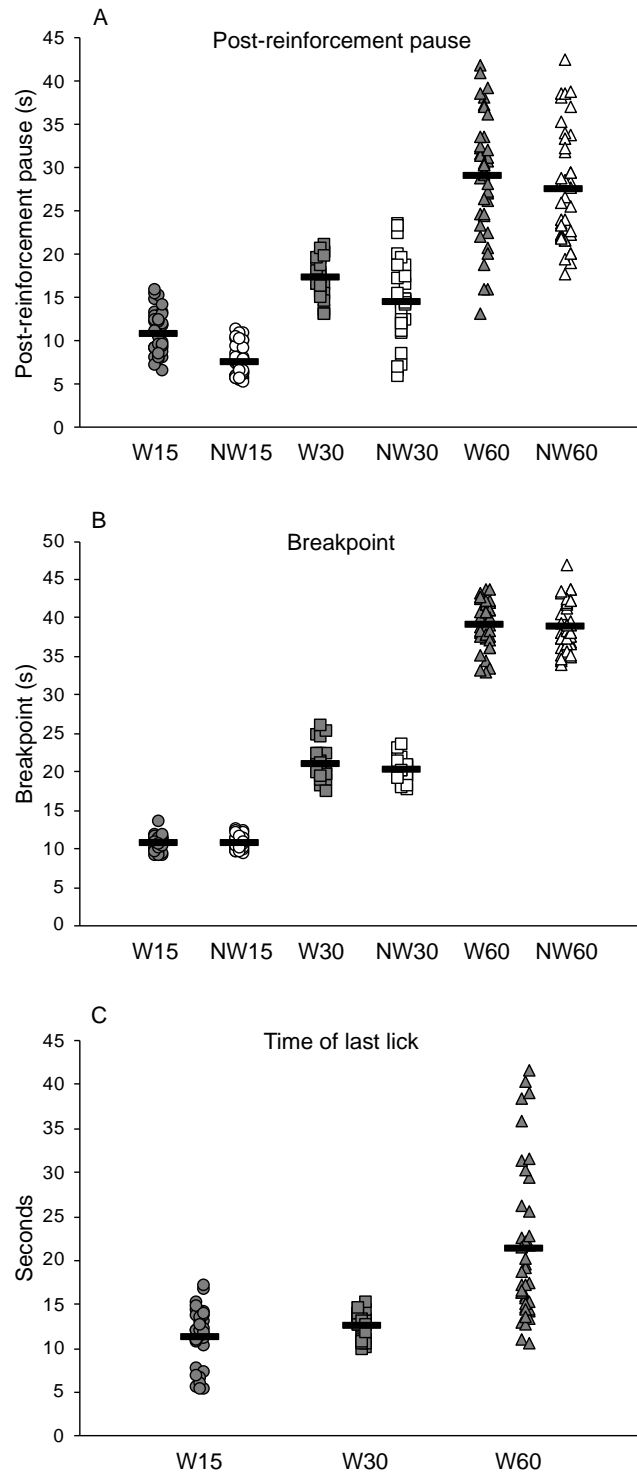
Mean lever-pressing and spout-licking rates



Note. A: mean lever-pressing rate for each session and group throughout the experiment. B: mean spout-licking rate for each group and session. Vertical bars denote standard error of the mean.

Figure 2*Distribution of lever presses and spout licks*

Note. Superposed distributions of spout-licking (y-axis on the left) and lever-pressing (y-axis on the right) mean rates in 1 s bins along inter-reinforcement intervals. Data are from the last five sessions of the experiment. A: FI 15 s; B: FI 30 s; C: FI 60 s. Vertical bars denote standard error of the mean.

Figure 3*Post-reinforcement pauses, breakpoints and times of the last lick*

Note. Each symbol shows the value of each measure in each of the last five sessions of the experiment for each subject. The black horizontal lines represent the mean of the group.